Freescale Semiconductor

MPC509UM/AD

POWERRISCCONTROL™

MPC500 Family

MPC509
User's Manual

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How to Reach Us:

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support@freescale.com

USA/Europe or Locations Not Listed:
Freescale Semiconductor
Technical Information Center, CH370
1300 N. Alma School Road
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+1-800-521-6274 or +1-480-768-2130
support@freescale.com

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor Hong Kong Ltd.
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PREFACE

This manual defines the functionality of the MPC509 for use by software and hardware developers. The MPC509 is a member of the PowerPC-based Motorola MPC500 family of microcontrollers.

Audience

This manual is intended for system software and hardware developers and applications programmers. It is assumed that the reader understands operating systems, microprocessor and microcontroller system design, and the basic principles of RISC processing.

Additional Reading

This section lists additional reading that provides background to or supplements the information in this manual.

- John L. Hennessy and David A. Patterson, *Computer Architecture: A Quantitative Approach*, Morgan Kaufmann Publishers, Inc., San Mateo, CA
- *PowerPC Microprocessor Family: the Programming Environments* (MPCFPE/AD)
- *RCPU Reference Manual* (RCPURM/AD)
- *SIU Reference Manual* (SIURM/AD)
- Additional Motorola MPC500-Family documentation. Refer to Motorola publication *Advanced Microcontroller Unit (AMCU) Literature* (BR1116/D) for a complete listing of documentation.

Conventions

This document uses the following notational conventions:

ACTIVE_HIGH	Names for signals that are active high are shown in uppercase text without an overbar. Signals that are active high are referred to as asserted when they are high and negated when they are low.
$\overline{\text{ACTIVE\_LOW}}$	A bar over a signal name indicates that the signal is active low. Active-low signals are referred to as asserted (active) when they are low and negated when they are high.

mnemonics	Instruction mnemonics are shown in lowercase bold.
italics	Italics indicate variable command parameters, for example, **bcctr***x*
0x0F	Hexadecimal numbers
0b0011	Binary numbers
rA|0	The contents of a specified GPR or the value zero.
REG[FIELD]	Abbreviations or acronyms for registers are shown in uppercase text. Specific bit fields or ranges are shown in brackets.
x	In certain contexts, such as a signal encoding, this indicates a don't care. For example, if a field is binary encoded 0bx001, the state of the first bit is a don't care.

Nomenclature

Logic level one is the voltage that corresponds to Boolean true (1) state.

Logic level zero is the voltage that corresponds to Boolean false (0) state.

To **set** a bit or bits means to establish logic level one on the bit or bits.

To **clear** a bit or bits means to establish logic level zero on the bit or bits.

A signal that is **asserted** is in its active logic state. An active low signal changes from logic level one to logic level zero when asserted, and an active high signal changes from logic level zero to logic level one.

A signal that is **negated** is in its inactive logic state. An active low signal changes from logic level zero to logic level one when negated, and an active high signal changes from logic level one to logic level zero.

LSB means least significant bit or bits. **MSB** means most significant bit or bits. References to low and high bytes are spelled out.

SECTION 1
INTRODUCTION

The MPC509 is a member of the PowerPC Family of reduced instruction set computer (RISC) microcontrollers (MCUs). The MPC509 implements the 32-bit portion of the PowerPC™ architecture, which provides 32-bit effective addresses, integer data types of eight, 16, and 32 bits, and floating-point data types of 32 and 64 bits.

The RISC MCU processor (RCPU) integrates four execution units: an integer unit (IU), a load/store unit (LSU), a branch processing unit (BPU), and a floating-point unit (FPU). The RCPU is capable of issuing one sequential (non-branch) instruction per clock. In addition, branch instructions are evaluated ahead of time when possible, resulting in zero-cycle execution time for many branch instructions. Instructions can complete out of order for increased performance; however, the MPC509 makes them appear sequential.

The MPC509 includes an on-chip, 4-Kbyte, two-way set associative, physically addressed instruction cache, chip-select logic to reduce or eliminate external decoding logic, four Kbytes of static RAM, and extensive processor debugging functionality.

The MPC509 has a high-bandwidth, 32-bit data bus and a 32-bit address bus. The MCU supports 16-bit and 32-bit memories and both single-beat and burst data memory accesses.

The MPC509 is available in a 3 V-only I/O configuration (part number MPC509L) and in a TTL-compatible 5 V-friendly I/O configuration (part number MPC509L3).

1.1 Features

- Fully-Integrated Single-Chip Microcontroller
- RISC MCU Central Processing Unit (RCPU)
  - — 32-Bit PowerPC Architecture (Compliant with PowerPC Architecture Book 1)
  - — Single-Issue Processor
  - — Integrated Floating-Point Unit
  - — Branch Prediction for Prefetch
  - — 32 Bit x 32 Bit General-Purpose Register File
  - — 32 Bit x 64 Bit Floating-Point Register File
  - — Precise Exception Model
  - — Internal Harvard Architecture: Load/Store Bus (L-Bus), Instruction Bus (I-Bus)
  - — PowerPC Time Base and Decrementer
- System Interface Unit (SIU)
  - — Chip-Select Logic to Reduce or Eliminate External Decoding Logic
  - — External Bus Interface (EBI) that Supports Synchronous, Asynchronous, Burst Transfer, and Pipeline Transfer Memory Types
  - — System Protection Features Including Bus Monitor and Periodic Interrupt Timer

— On-Chip Phase-Locked Loop (PLL), 16 MHz to 44 MHz
— Five Dual-Purpose I/O Ports, Two Dual-Purpose Output Ports
• Peripheral Control Unit (PCU)
— Software Watchdog
— Interrupt Controller to Manage External and Internal Interrupts to the CPU
— Dual-Purpose I/O Port
— L-Bus IMB Interface (LIMB) Connecting L-Bus to Intermodule Bus 2 (IMB2)
• 4-Kbyte On-Chip Instruction Cache (I-Cache)
• 4-Kbyte On-Chip Static Data RAM (SRAM)
• 3.3-V Supply Voltage
• Tolerates Input Signals from 5-V Peripherals

1.2 Block Diagram

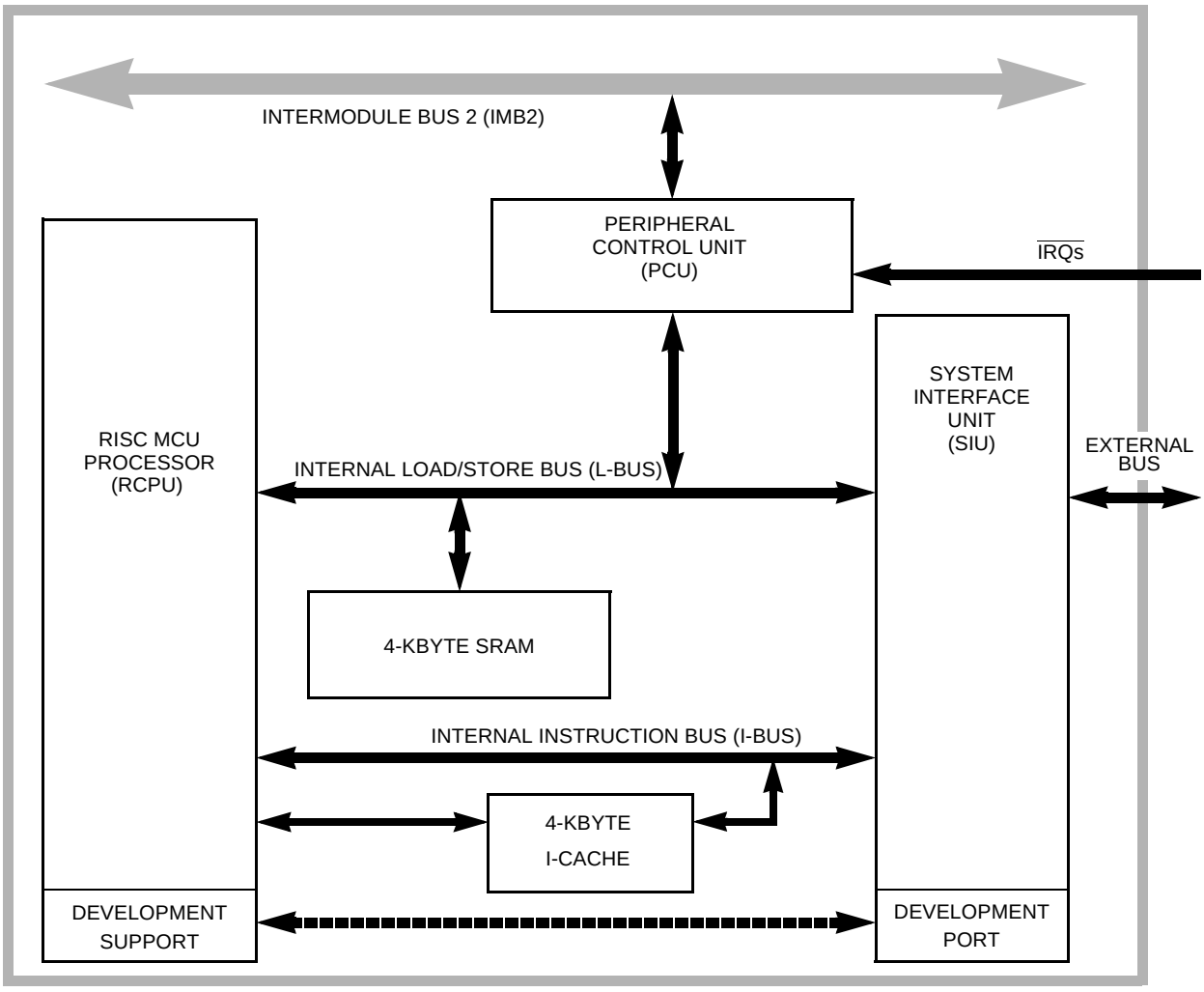


Figure 1-1 MPC509 Block Diagram

Notice in **Figure 1-1** that the IMB2 connects the processor to any on-chip peripherals. No such peripherals are present on the MPC509.

1.3 Pin Connections

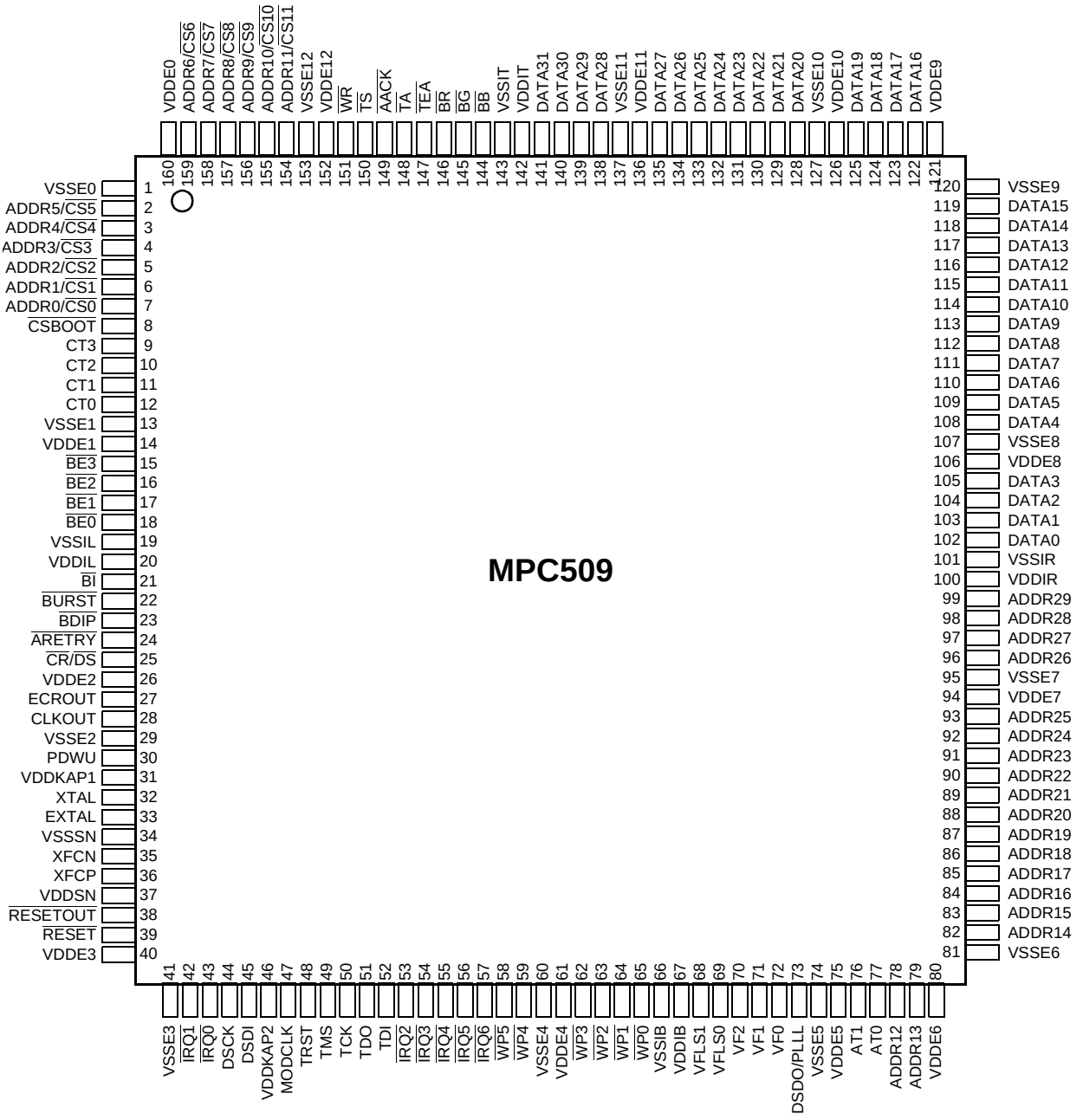


Figure 1-2 MPC509 Pin Assignments

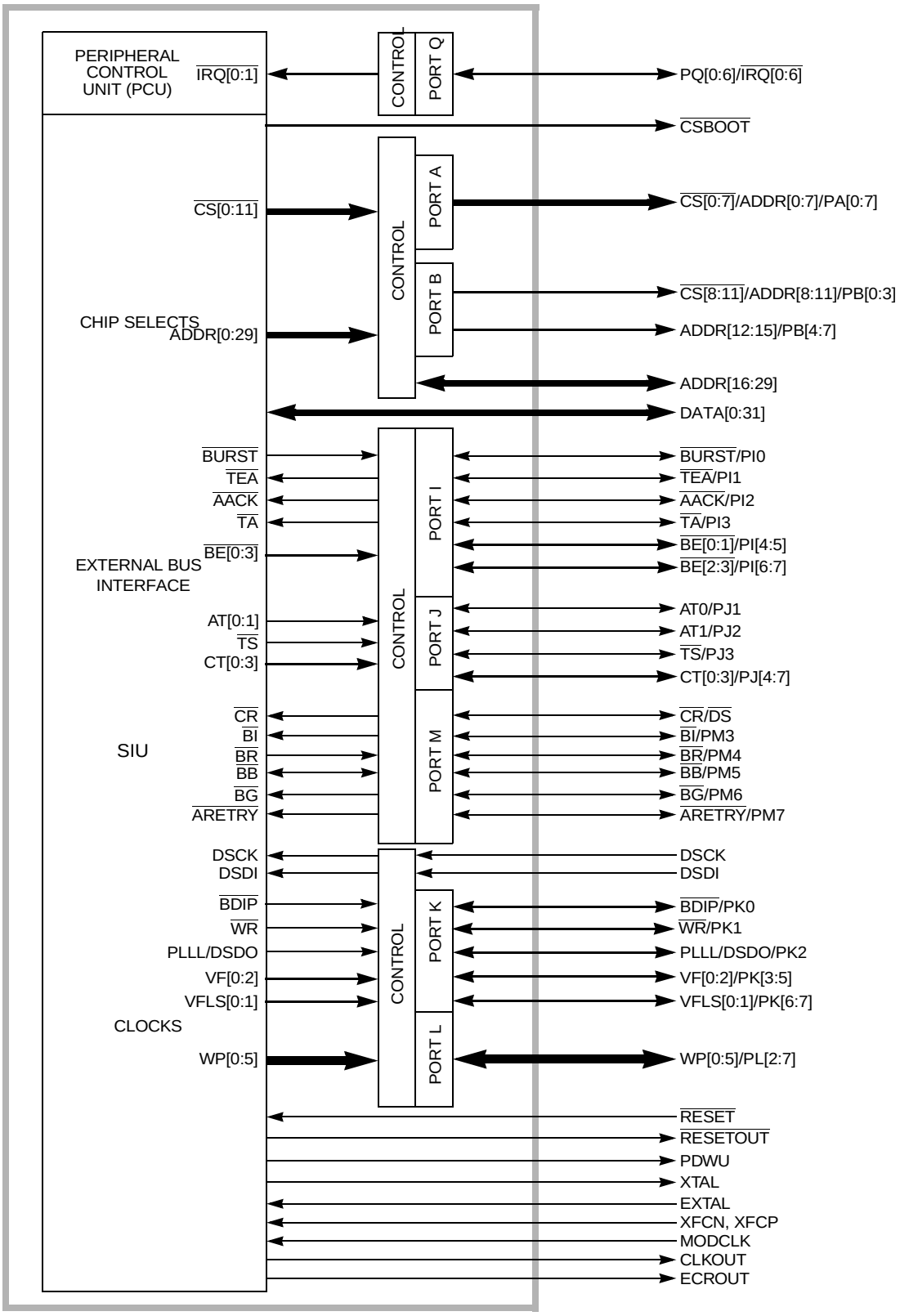


Figure 1-3 MPC509 Signals

1.4 Memory Map

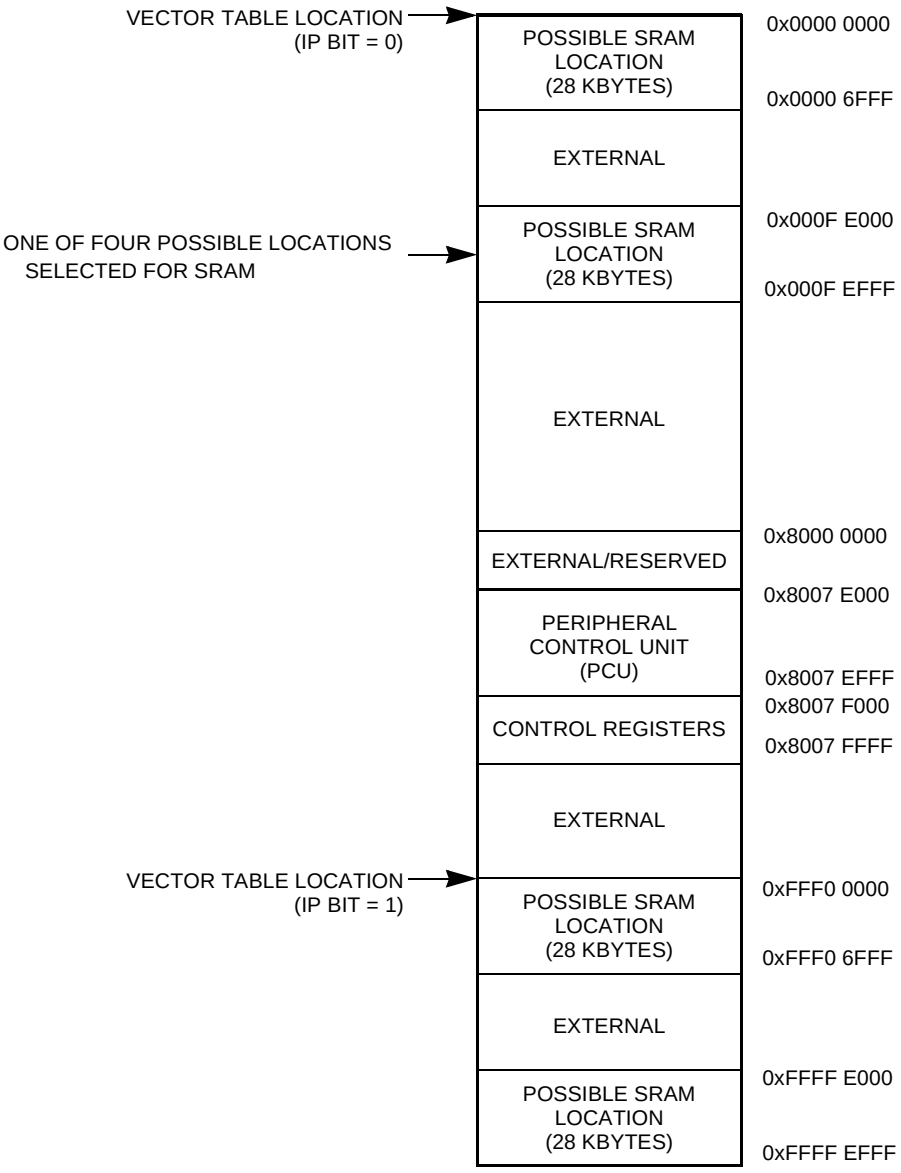


Figure 1-4 MPC509 Memory Map

The MPC family has a unified memory map including instruction memory (I-Mem), load/store memory (L-Mem), and all memory-mapped registers. I-Mem resides on the instruction bus; L-Mem resides on the load/store bus. The locations of I-Mem and L-Mem are selected in the MEMMAP register located in the SIU. In the MPC509, the SRAM module serves as L-Mem. The MPC509 has no I-Mem module.

SECTION 2
SIGNAL DESCRIPTIONS

This section describes the MPC509 signals and pins. For a more detailed discussion of a particular signal, refer to the section of the manual that discusses the function involved.

2.1 Pin List

Table 2-1 MPC509 Pin List

Primary Function(s)	Port Function
Address Bus, Data Bus, Chip Selects	
ADDR[0:11]/$\overline{\text{CS}}$[0:11]	PA[0:7], PB[0:3]
ADDR[12:15]	PB[4:7]
ADDR[16:29]	—
DATA[0:31]	—
$\overline{\text{CSBOOT}}$	—
Bus Control, Clock, Development Support	
$\overline{\text{BURST}}$, $\overline{\text{TEA}}$, $\overline{\text{AACK}}$, $\overline{\text{TA}}$, $\overline{\text{BE}}$[0:1], $\overline{\text{BE2}}$/ADDR30, $\overline{\text{BE3}}$	PI[0:7]
AT[0:1], $\overline{\text{TS}}$, CT[0:3]	PJ[1:7]
$\overline{\text{BDIP}}$, $\overline{\text{WR}}$, PLLL/DSDO, VF[0:2], VFLS[0:1]	PK[0:7]
$\overline{\text{WP}}$[0:5]	PL[2:7]
$\overline{\text{BI}}$, $\overline{\text{BR}}$, $\overline{\text{BB}}$, $\overline{\text{BG}}$, $\overline{\text{ARETRY}}$	PM[3:7]
$\overline{\text{CR}}$/$\overline{\text{DS}}$	—
DSCK, DSDI	—
XTAL, EXTAL, XFCN, XFCP, CLKOUT, ECROUT, PDWU, MODCLK	—
Reset, Interrupts	
$\overline{\text{RESET}}$, $\overline{\text{RESETOUT}}$	—
$\overline{\text{IRQ}}$[0:6]	PQ[0:6]
Test	
TDI, TDO, TCK, TMS, TRST	—
Power	
V_{DDSN}, V_{SSSN}	—
V_{DDI}, V_{SSI}	—
V_{DDE}, V_{SSE}	—
VDDKAP1, VDDKAP2	—

2.2 Pin Characteristics

Table 2-2 shows the characteristics of the MPC509 pins. Assume the model for output only and three-state I/O buffers shown in **Figure 2-1**.

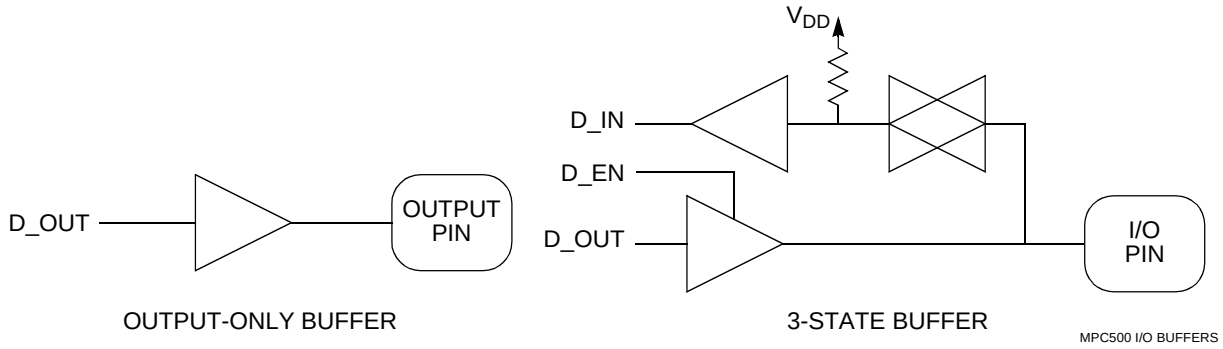


Figure 2-1 Output-Only and Three-State I/O Buffers

Table 2-2 EBI Pin Definitions

Mnemonic	Buffer Type	Weak Pull-Up[1]	When Bus is Granted	When Bus Is Not Granted	During Reset
Address and Data Bus					
$\overline{\text{CS}}$[0:11]/ ADDR[0:11]	Output only	No	Driven	Driven high	Initially high, changes five clock cycles after reset source is negated
ADDR[12:29]	3-state	No	Driven unless configured as input port	Float unless configured as output port	Float
DATA[0:31]	3-state	No	Driven if write, float if read	Float unless configured as output port	Float
Transfer Attributes					
$\overline{\text{WR}}$	3-state	No	Output unless configured as input ports	Float unless configured as output port	Float
$\overline{\text{BURST}}$	3-state	No			
$\overline{\text{BE}}$[0:3]	3-state	No			
AT[0:1]	3-state	No			
CT[0:3]	3-state	No			
Transfer Handshakes					
$\overline{\text{TS}}$	3-state	No	Output unless configured as input port	Float unless configured as output port	Input port; output three-stated
$\overline{\text{AACK}}$	3-state	Yes	Input unless configured as an output port	Float unless configured as output port	Input port; output three-stated
$\overline{\text{BDIP}}$/$\overline{\text{LAST}}$	3-state	No	Output unless configured as input port	Float unless configured as output port	Input port. After reset, driven by CPU
$\overline{\text{BI}}$	3-state	Yes	Input unless configured as output port		Float
$\overline{\text{TA}}$	3-state	Yes	Input unless configured as an output port	Float (listen only); only driven if configured as output port	Input port; output three-stated

Table 2-2 EBI Pin Definitions (Continued)

Mnemonic	Buffer Type	Weak Pull-Up[1]	When Bus is Granted	When Bus Is Not Granted	During Reset
$\overline{TEA}$	3-state	Yes	Input unless configured as an output port	Float (listen only); only driven if configured as output port	Input port; output three-stated
$\overline{ARETRY}$	3-state	Yes	Input unless configured as output port	Input; driven if configured as output port	Input port; output three-stated
Arbitration					
$\overline{BR}$	3-state	No	Output unless configured as input port. Not affected by $\overline{BG}$.		Float
$\overline{BG}$	3-state	Weak pull-down	Input unless configured as output port	Output only if configured as output port	Float
$\overline{BB}$	3-state	Yes	Output unless configured as input port	If relinquishing drive high then float unless configured as output port	Float
Miscellaneous					
$\overline{CR}/\overline{DS}$	3-state	Yes	Not affected by $\overline{BG}$. Input unless configured for secondary function		Float
$\overline{RESETOUT}$	Output	No	Not affected by $\overline{BG}$		—
$\overline{RESET}$	Input	No	Not affected by $\overline{BG}$		—
CLKOUT	Output	No	Not affected by $\overline{BG}$		Not affected

NOTES:
1. Weak pull-ups can maintain an internal logic level one but may not maintain a logic level one on external pins.

2.3 Power Connections

Table 2-3 shows the MPC509 power connections.

Table 2-3 MPC509 Power Connections

Pin	Description
V_{DDE}, V_{SSE}	External periphery power
V_{DDI}, V_{SSI}	Internal module power
V_{DDSN}, V_{SSSN}	Clock synthesizer power
VDDKAP1	Keep-alive power for the internal oscillator, time base, and decrementer
VDDKAP2	Keep-alive power for the SRAM array

CAUTION

The keep-alive power pins (VDDKAP1 and VDDKAP2) must be powered up before or at the same time as V_{DD} (V_{DDI}, V_{DDE}, and V_{DDSN}). Otherwise, an excessive draw may result.

2.4 Pins with Internal Pull-Ups and Pulldowns

Table 2-4 lists MPC509 pins with internal pull-ups or pulldowns.

Table 2-4 Pins with Internal Pull-Ups/Pulldowns

Pin	Pull-Up/Pulldown
$\overline{TA}$	Pull-Up
$\overline{TEA}$	
$\overline{AACK}$	
$\overline{ARETRY}$	
$\overline{CR}$	
$\overline{BI}$	
$\overline{BB}$	
$\overline{IRQ[0:6]}$	
TMS	
$\overline{TRST}$	
TDI	
$\overline{BG}$	Pulldown
DSCK	
DSDI	
TCK	

2.5 Signal Descriptions

MPC509 signals are summarized in **Table 2-5** and described in the following subsections. Since pins often have more than one function, more than one description may apply to a pin.

Table 2-5 Signal Descriptions

Mnemonic	Module	Direction	Description
ADDR[0:29]	EBI	Output	32-bit address bus. Driven by the bus master to index the bus slave. Low-order bit (ADDR31) not pinned out — use byte enables instead. BE2 functions as ADDR30 during accesses to 16-bit ports.
$\overline{AACK}$	EBI	Input	Address acknowledge. When asserted, indicates the slave has received the address from the bus master.
$\overline{ARETRY}$	EBI	Input	When asserted, indicates the master needs to retry its address phase.
AT[0:1]	EBI	Output	Address types. Define addressed space as user or supervisor, data or instruction.
$\overline{BB}$	EBI	Input/Output	Bus busy. Asserted by current bus master to indicate the bus is currently in use. Prospective new master should wait until the current master negates this signal.
$\overline{BDIP}$	EBI	Output	Burst data in progress. Asserted at the beginning of a burst cycle and negated prior to the last beat. This signal can be negated prior to the end of a burst to terminate the burst data phase early.
$\overline{BE[0:3]}$	EBI	Output	Byte enables. One byte enable per byte lane of the data bus.
$\overline{BG}$	EBI	Input	Bus grant. When asserted by bus arbiter, the bus is granted to the bus master. Each master has its own bus grant signal.
$\overline{BI}$	EBI	Input	Burst inhibit. When asserted, indicates the slave does not support burst mode.
$\overline{BR}$	EBI	Output	Bus request. When asserted, indicates the potential bus master is requesting the bus. Each master has its own bus request signal.

Table 2-5 Signal Descriptions (Continued)

Mnemonic	Module	Direction	Description
$\overline{\text{BURST}}$	EBI	Output	If asserted, indicates cycle is a burst cycle.
CLKOUT	EBI	Output	Continuously-running clock. All signals driven on the E-bus must be synchronized to the rising edge of this clock.
$\overline{\text{CR}}$	EBI	Input	Cancel reservation. Each RCPU has its own $\overline{\text{CR}}$ signal. When asserted, instructs the bus master to clear its reservation.
$\overline{\text{CSBOOT}}$	Chip Selects	Output	Chip select of system boot memory.
$\overline{\text{CS[0:11]}}$	Chip Selects	Output	Chip-select signals for external memory devices.
CT[0:3]	EBI	Output	Cycle type signals. Indicate what type of bus cycle the bus master is initiating.
DATA[0:31]	EBI	Input/Output	32-bit data bus.
$\overline{\text{DS}}$	EBI	Output	Data strobe. Asserted by EBI at the end of a chip-select-controlled bus cycle after the chip-select unit asserts the internal $\overline{\text{TA}}$ signal or the bus monitor timer asserts the internal $\overline{\text{TEA}}$ signal. Also asserted at the end of a show cycle. Used primarily by development tools.
DSCK	Dev. Support	Input	Development serial clock. Used to clock data shifted into or out of development serial port.
DSDI	Dev. Support	Input	Development serial data in. Used to shift development serial data into the development port shift register.
DSDO	Dev. Support	Output	Development serial data out. Used to shift development serial data out of the development port shift register.
ECROUT	Clocks	Output	Provides a clock reference output with a frequency equal to the crystal oscillator frequency, taken from the PLL feedback signal.
EXTAL	Clocks	Input	Connection for external crystal to the internal oscillator circuit, or clock input.
$\overline{\text{IRQ[0:6]}}$	PCU	Input	Interrupt request inputs.
MODCLK	Clocks	Input	Clock mode. The state of this signal and that of V_{DDSN} during reset determine the source of the system clock (normal operation, 1:1 mode, PLL bypass mode, or special test mode). Refer to **Table 5-32** in **SECTION 5 SYSTEM INTERFACE UNIT** for details.
PA[0:7]	Ports	Output	Port A discrete output signals.
PB[0:7]	Ports	Output	Port B discrete output signals.
PDWU	Clocks	Output	Power-down wakeup to external power-on reset circuit.
PI[0:7]	Ports	Input/Output	Port I discrete input/output signals.
PJ[0:7]	Ports	Input/Output	Port J discrete input/output signals.
PK[0:7]	Ports	Input/Output	Port K discrete input/output signals.
PL[2:7]	Ports	Input/Output	Port L discrete input/output signals.
PM[3:7]	Ports	Input/Output	Port M discrete input/output signals.
PQ[0:6]	PCU	Input/Output	Port Q discrete input/output signals.
PLLL	Clock	Output	Indicates whether phase-locked loop is locked.
$\overline{\text{RESET}}$	EBI	Input	Hard reset. When asserted, devices on the bus must reset.
$\overline{\text{RESETOUT}}$	EBI	Output	Reset output signal. Asserted by MCU during reset. When asserted, instructs all devices monitoring this signal to reset all parts within themselves that can be reset by software.
$\overline{\text{TA}}$	EBI	Input	Transfer acknowledge. When asserted, indicates the slave has received the data during a write cycle or returned the data during a read cycle.

Table 2-5 Signal Descriptions (Continued)

Mnemonic	Module	Direction	Description
TCK	JTAG	Input	Test clock input with a pull-down resistor to synchronize the test logic.
TDI	JTAG	Input	Test data input with a pull-up resistor sampled on the rising edge of TCK.
TDO	JTAG	Output	Three-statable test data output that changes on the falling edge of TCK.
$\overline{TEA}$	EBI	Input	Transfer error acknowledge. Asserted by an external device to signal a bus error condition.
TMS	JTAG	Input	Test mode select input with a pull-up resistor. Sampled on the rising edge of TCK to sequence the test controller's state machine.
$\overline{TRST}$	JTAG	Input	Asynchronous active-low test reset with a pull-up resistor that provides initialization of the TAP controller and other logic as required by the standard.
$\overline{TS}$	EBI	Output	Transfer start. When asserted, indicates the start of a bus cycle.
V_{DDSN}	Clocks	Input	Power supply input to the VCO. In addition, the state of this signal and that of MODCLK during reset determine the source of the system clock (normal operation, 1:1 mode, PLL bypass mode, or special test mode). Referto **Table 5-32** in **SECTION 5 SYSTEM INTERFACE UNIT** for details.
VF[0:2]	Dev. Support	Output	Denotes the last fetched instruction or how many instructions were flushed from the instruction queue.
VFLS[0:1]	Dev. Support	Output	Denotes how many instructions are flushed from the history buffer during the current clock cycle. Also indicates freeze state.
V_{SSSN}	Clocks	Input	Power ground input to the VCO.
WP[0:5]	Dev. Support	Output	Output signals for I-bus watchpoints (WP[0:3]) and L-bus watchpoints (WP[4:5]).
XTAL	Clocks	Output	Connection for external crystal to the internal oscillator circuit.
$\overline{WR}$	EBI	Output	Asserted (low): write cycle. Negated (high): read cycle.
XFCN, XFCP	Clocks	Input	Used to add an external capacitor to the filter circuit of the phase-locked loop.

2.5.1 Bus Arbitration and Reservation Support Signals

The bus arbitration signals request the bus, recognize when the request is granted, and indicate to other devices when mastership is granted. There are no separate arbitration phases for the address and data buses. For a detailed description of how these signals interact, see 5.4.5.1 Arbitration Phase.

The cancel reservation ($\overline{CR}$) signal is used to indicate that the processor should not perform any **stwcx.** cycle to external memory. This signal is sampled at the same time the MCU samples the arbitration pins for a qualified bus grant.

2.5.1.1 Bus Request ($\overline{BR}$)

Output only
Module: EBI

State Meaning Asserted — Indicates the potential bus master is requesting the bus. Each master has its own bus request signal. The SIU asserts $\overline{BR}$ to request bus mastership if its bus

grant ($\overline{BG}$) pin is not already asserted and the bus busy ($\overline{BB}$) has not been negated by the current bus master.

The SIU assumes mastership of the external bus only after receiving a qualified bus grant. This occurs when the bus arbiter asserts $\overline{BG}$ to the SIU and the $\overline{BB}$ pin has also been negated by the previous bus master. The SIU cannot start a cycle on the external bus if the current master is holding the $\overline{BB}$ pin asserted, even if the SIU has received a bus grant ($\overline{BG}$ asserted) from the bus arbiter.

Negated — Indicates the MCU is not requesting the address bus. The MCU may have no bus operation pending, it may be parked, or the MCU may be in the process of releasing the bus in response to $\overline{ARETRY}$.

Timing Comments

Assertion — Occurs when the MCU is not parked and a bus transaction is needed.

Negation — Occurs as soon as the SIU starts a bus cycle after receiving a qualified bus grant.

2.5.1.2 Bus Grant ($\overline{BG}$)

Input only
Module: EBI

State Meaning

Asserted — (By bus arbiter) indicates the bus is granted to the requesting device. The signal can be kept asserted to allow the current master to park the bus. Single-master systems can tie this signal low permanently.

Negated — Indicates the requesting device is not granted bus mastership.

Timing Comments

Assertion — May occur at any time to indicate the MCU is free to use the address bus. After the MCU assumes bus mastership, it does not check for a qualified bus grant again until the cycle during which the address bus tenure is completed (assuming it has another transaction to run). The MCU does not accept a $\overline{BG}$ in the cycles between the assertion of any $\overline{TS}$ and $\overline{AACK}$.

Negation — May occur at any time to indicate the MCU cannot use the bus. The MCU may still assume bus mastership on the clock cycle of the negation of $\overline{BG}$ because during the previous cycle $\overline{BG}$ indicated to the MCU that it was free to take mastership (if qualified).

2.5.1.3 Bus Busy ($\overline{BB}$)

Input/Output
Module: EBI

State Meaning

Asserted — The current bus master asserts this signal to indicate the bus is currently in use. The prospective new master must wait until the current master negates this signal.

Negated — Indicates that the bus is not owned by another bus master and that the bus is available to the MCU when accompanied by a qualified bus grant.

Timing Comments

Assertion — $\overline{BB}$ is asserted during the address phase of each external bus cycle, if it was previously negated. It remains asserted between internal atomic cycles (any non-burst word accesses to an external 16-bit port).

Negation — Occurs during the clock cycle following termination of the data phase of an external bus cycle. The signal is negated for half a clock cycle and then placed in a high-impedance state.

2.5.1.4 Cancel Reservation ($\overline{CR}$)

Input only
Module: EBI

State Meaning

Asserted — (By an external bus arbiter or reservation snooping logic) indicates that there is no outstanding reservation on the external bus. Each RCPU has its own $\overline{CR}$ signal. Assertion indicates that the processor should not perform any **stwcx.** cycle to external memory.

Negated — Indicates there is an outstanding reservation on the external bus.

Timing Comments

Assertion — Can occur at any rising edge of the bus clock. This signal is sampled at the same time the MCU samples the arbitration pins for a qualified bus grant prior to starting a bus cycle.

2.5.2 Address Phase Signals

The address phase is the period of time from the assertion of transfer start ($\overline{TS}$) until the address phase is terminated by one of the following signals: address acknowledge ($\overline{AACK}$), address retry ($\overline{ARETRY}$), or transfer error acknowledge ($\overline{TEA}$). $\overline{TS}$ is valid for one clock cycle at the start of the address phase. The address bus and the address attributes described below are valid for the duration of the address phase. Refer to 5.4.5.2 Address Phase for additional information on address phase signals.

2.5.2.1 Address Bus (ADDR[0:29])

Output only
Module: EBI

State Meaning Asserted/Negated — Represents the physical address of the data to be transferred. Driven by the bus master to index the bus slave. Low-order bit (ADDR31) is not pinned out; byte enable signals (BE[0:3]) are used instead (see **Table 2-6**). During accesses to 16-bit ports, $\overline{BE2}$ pin provides ADDR30 signal.

Timing Comments Assertion/Negation — Occurs one clock cycle after a qualified bus grant. Coincides with assertion of $\overline{BB}$ and $\overline{TS}$.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.2 Write/Read ($\overline{WR}$)

Output only
Module: EBI

State Meaning Asserted/Negated — This signal is driven high for a read cycle and low for a write cycle.

Timing Comments Assertion/Negation — $\overline{WR}$ is an address attribute; it is updated at the start of the address phase and maintained until the start of the next address phase. Note that for pipelined accesses, it is not valid during the data phase.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.3 Burst Indicator ($\overline{BURST}$)

Output only
Module: EBI

State Meaning Asserted — indicates a burst cycle. If a burst access is burst-inhibited by the slave, $\overline{BURST}$ is driven during each single-beat (decomposed) cycle.

Negated — Indicates current cycle is not a burst cycle.

Timing Comments Assertion/Negation — $\overline{BURST}$ is an address attribute; it is updated at the start of the address phase and maintained until the start of the next address phase.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.4 Byte Enables ($\overline{BE[0:3]}$)

Output only
Module: EBI

State Meaning $\overline{BE[0:3]}$ indicate which byte within a word is being accessed. External memory chips can use these signals to determine which byte location is enabled. **Table 2-6** explains the encodings during accesses to 32-bit and 16-bit ports.

Table 2-6 Byte Enable Encodings

Byte Enable	Use During 32-Bit Port Access	Use During 16-Bit Port Access
$\overline{BE0}$	Byte enable for DATA[0:7]	Byte enable for DATA[0:7]
$\overline{BE1}$	Byte enable for DATA[8:15]	Byte enable for DATA[8:15]
$\overline{BE2}$	Byte enable for DATA[16:23]	ADDR30
$\overline{BE3}$	Byte enable for DATA[24:31]	0 = Operand size is word 1 = Operand size is byte or half-word

Timing Comments Assertion/Negation — The $\overline{BE[0:3]}$ signals are address attributes; they are updated at the start of the address phase and maintained until the start of the next address phase.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.5 Transfer Start ($\overline{TS}$)

Output only
Module: EBI

State Meaning Asserted — Indicates the start of a bus cycle.

Timing Comments Assertion — Coincides with the assertion of $\overline{BB}$.

Negation — Occurs one clock cycle after $\overline{TS}$ is asserted.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.6 Address Acknowledge ($\overline{AACK}$)

Input only
Module: EBI

State Meaning Asserted — Indicates that the address phase of a transaction is complete.

If the external access is to a chip-select region for which the chip select is programmed to return $\overline{AACK}$ and $\overline{TA}$, then the external bus interface uses the logical OR of the external $\overline{AACK}$ pin and the $\overline{AACK}$ signal returned by the chip select. If the chip select returns $\overline{AACK}$, it is not visible on the exter-

nal pins.

Negated — (While the MCU is driving $\overline{BB}$) indicates that the address bus and the transfer attributes must remain driven.

Timing Comments

Assertion — May occur as early as the clock cycle after $\overline{TS}$ is asserted; assertion can be delayed to allow adequate address access time for slow devices. $\overline{AACK}$ should be asserted at the same time as or prior to the assertion of $\overline{TA}$. If $\overline{AACK}$ is returned prior to the assertion of $\overline{TA}$, the SIU can initiate another cycle while the previous cycle is still in progress; that is, returning $\overline{AACK}$ early allows pipelining of bus cycles.

Negation — Must occur one clock cycle after the assertion of $\overline{AACK}$.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.7 Burst Inhibit ($\overline{BI}$)

Input only
Module: EBI

State Meaning

Asserted — Indicates the addressed device does not have burst capability. When this signal is asserted, the SIU decomposes the transfer into multiple cycles, incrementing the address for each cycle.

For systems that do not use burst mode at all, this signal can be tied low permanently.

Negated — Indicates the device supports burst mode, or that the $\overline{BI}$ signal is being sent by the chip-select unit. For systems that use SIU chip selects with all external memory, the $\overline{BI}$ pin can remain negated; the chip-select unit can be programmed to assert $\overline{BI}$ to prevent bursts.

Timing Comments

Assertion/Negation — Sampled when $\overline{AACK}$ is asserted. A burst transfer can only be burst-inhibited before the first $\overline{TA}$ assertion.

Simple, asynchronous memory devices should keep $\overline{AACK}$ negated to keep the address valid. They can assert $\overline{BI}$ at the same time as or before $\overline{AACK}$ and at the same time as the first $\overline{TA}$ assertion.

Synchronous, pipelineable memory devices that do not support bursting should return $\overline{BI}$ with $\overline{AACK}$ as soon as they are ready to receive the next address.

Burstable memory devices should negate $\overline{BI}$ at the same time as or before they assert $\overline{AACK}$.

2.5.2.8 Address Retry ($\overline{ARETRY}$)

Input only
Module: EBI

State Meaning

Asserted — If the MCU is the bus master, $\overline{ARETRY}$ indicates that the MCU must retry the preceding address phase. The MCU will not begin a bus cycle for the clock cycle following assertion of $\overline{ARETRY}$. Note that the subsequent address retried may not be the same one associated with the assertion of the $\overline{ARETRY}$ signal. Assertion of $\overline{ARETRY}$ overrides the assertion of $\overline{AACK}$.

Negated/High Impedance — Indicates that the MCU does not need to retry the last address phase.

Timing Comments

Assertion — Must occur at least one clock cycle following the assertion of $\overline{TS}$ if a retry is required. $\overline{TA}$ or $\overline{TEA}$ must not be asserted during a cycle in which $\overline{ARETRY}$ is asserted. If $\overline{TA}$ is asserted for any part of a burst cycle, $\overline{ARETRY}$ must not be asserted at any time during the cycle; if $\overline{ARETRY}$ is asserted during a burst cycle, it must be asserted before the first beat is terminated with $\overline{TA}$.

Note that $\overline{BB}$ is not negated until the second clock cycle after $\overline{ARETRY}$ assertion.

Negation — Must occur one clock cycle after assertion of $\overline{ARETRY}$.

2.5.2.9 Address Type (AT[0:1])

Output only
Module: EBI

State Meaning

Asserted/Negated — AT[0:1] define the addressed space as user or supervisor and as data or instruction, as shown in **Table 2-7**.

Table 2-7 Address Type Definitions

AT[0:1]	Address Space Definition
0b00	User, data
0b01	User, instruction
0b10	Supervisor, data
0b11	Supervisor, instruction

Timing Comments Assertion/Negation — The AT[0:1] signals are address attributes; they are updated at the start of the address phase and maintained until the start of the next address phase.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.2.10 Cycle Types (CT[0:3])

Output only
Module: EBI

State Meaning Asserted/Negated — Cycle type signals. Indicate what type of bus cycle the bus master is initiating. Refer to **Table 5-14** in SECTION 5 SYSTEM INTERFACE UNIT for cycle type encodings.

Timing Comments Assertion/Negation — The CT[0:3] signals are address attributes; they are updated at the start of the address phase and maintained until the start of the next address phase.

High impedance — Coincides with negation of $\overline{BB}$, provided no qualified bus grant exists.

2.5.3 Data Phase Signals

Depending on the state of the pipeline, the data phase starts either one clock cycle after the address phase starts, or as soon as the previous data phase completes. The data phase completes when it is terminated by transfer acknowledge ($\overline{TA}$) or transfer error acknowledge ($\overline{TEA}$). If the cycle is a burst cycle, then multiple $\overline{TA}$ assertions are required to terminate the data phase. Refer to 5.4.5.3 Data Phase for additional information on data phase signals.

2.5.3.1 Data Bus (DATA[0:31])

Input/output
Module: EBI

State Meaning Asserted/Negated — Represents the state of data during a read or write. 16-bit devices must reside on DATA[0:15]. 32-bit devices reside on DATA[0:31].

Timing Comments Assertion/negation — On write cycles, the SIU drives data one clock after driving $\overline{TS}$. The data is available until the slave asserts $\overline{TA}$.

During reads, the data must be available from the slave with $\overline{TA}$. The data bus is driven once for non-burst transactions and four times for burst transactions.

High impedance — The pins are placed in a high-impedance state during reads, or while the bus is idle, or when the

bus is arbitrated away. For write cycles, the high-impedance state occurs on the clock cycle after the final assertion of TA.

2.5.3.2 Burst Data in Progress (BDIP)

Output only
Module: EBI

State Meaning

Asserted — Indicates the data beat in front of the current one is needed by the master. This signal is asserted at the beginning of a burst data phase.

Negated — Indicates the final beat of a burst. This signal can be negated prior to the end of a burst to terminate the burst data phase early.

Timing Comments

Assertion/Negation — When the LST bit in the SIUMCR is set, BDIP uses the timing for the LAST signal. When LST is cleared, BDIP uses the timing for the BDIP signal. Refer to 5.5.16.6 Synchronous Burst Interface for more information.

High impedance — Coincides with negation of BB, provided no qualified bus grant exists.

2.5.3.3 Transfer Acknowledge (TA)

Input only
Module: EBI

State Meaning

Asserted — Indicates the slave has received the data during a write cycle or returned the data during a read cycle. Note that TA must be asserted for each data beat in a burst transaction.

If the external access is to a chip-select region for which the chip-select circuit is programmed to return AACK and TA, the EBI uses the logical OR of the external TA pin and the internal TA signal returned by the chip-select unit.

Negated — (While BB is asserted) indicates that, until TA is asserted, the MCU must continue to drive the data for the current write or must wait to sample the data for reads.

Timing Comments

Assertion — Must not occur before AACK is asserted for the current transaction. TA must not be asserted on cycles terminated by ARETRY and must not be asserted after the cycle has been terminated. The system can withhold assertion of TA to indicate that the MCU should insert wait states to extend the duration of the data beat.

Negation — Must occur after the clock cycle of the final (or

only) data beat of the transfer. For a burst transfer that is not under chip-select control, the system can assert TA for one clock cycle and then negate it to advance the burst transfer to the next beat and insert wait states during the next beat.

2.5.3.4 Transfer Error Acknowledge (TEA)

Input only
Module: EBI

State Meaning

Asserted — (By an external device) signals a bus error condition. TEA assertion terminates the data phase of the current bus cycle and overrides the assertion of TA. If AACK has not been asserted for the current bus cycle, TEA terminates both the address phase and the data phase.

This signal is intended for the cases of a write to a read-only address space or an access to a non-existent address. The signal can be output by a bus monitor timer or some system address protection mechanism, such as the chip-select logic.

Negated — Indicates that no external device has signaled a bus error.

Timing Comments

Assertion — May occur at any time during the address phase or data phase of a bus cycle.

Negation — Must occur one clock cycle after assertion of TEA.

2.5.3.5 Data Strobe (DS)

Output only
Module: EBI

State Meaning

Asserted — (By EBI) indicates the termination of a cycle from an internal source (TA or TEA assertion from the chip select unit, TEA assertion from the bus monitor, or a show cycle). DS can be used to latch data for a bus analyzer. It can also aid in following the external bus pipeline.

Timing Comments

Assertion — Occurs after the chip-select unit asserts the internal TA signal or the bus monitor timer asserts the internal TEA signal. DS is also asserted at the end of a show cycle.

2.5.4 Development Support Signals

2.5.4.1 Development Port Serial Data Out (DSDO)

Output only
Module: Development support

State Meaning Asserted/Negated — Indicates the logic level of data being shifted out of the development port shift register.

Timing Comments Transitions are relative to CLKOUT in self-clocked mode and relative to DSCK in clocked mode. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information.

2.5.4.2 Development Port Serial Data In (DSDI)

Input only
Module: Development support

State Meaning Asserted/Negated — Indicates the logic level of data being shifted into the development port shift register.

Reset Operation During reset, this pin functions as a reset configuration mode pin. If the pin is pulled high while the MCU asserts $\overline{\text{RESETOUT}}$, the data bus pins are used to configure the system when the reset state is exited. If the pin is low at the positive edge of $\overline{\text{RESETOUT}}$, then the system is configured by the internal default mode. Refer to 5.8.3 Configuration During Reset for more information on reset operation.

Timing Comments Transitions are relative to CLKOUT in self-clocked mode and relative to DSCK in clocked mode. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information.

2.5.4.3 Development Port Serial Clock Input (DSCK)

Input only
Module: Development support

State Meaning Asserted/Negated — Provides a clock signal for shifting data into or out of development serial port.

Reset Operation During reset, this pin functions as a debug mode enable pin. If the pin is pulled high while the MCU asserts $\overline{\text{RESETOUT}}$, debug mode is enabled when the reset state is exited. For normal operation, this pin should be pulled to ground through a resistor. Refer to 5.8.3 Configuration During Reset for more information.

Timing Comments Refer to the *RCPU Reference Manual* (RCPURM/AD) for detailed timing information.

2.5.4.4 Instruction Fetch Visibility Signals (VF[0:2])

Output only
Module: Development support

State Meaning Asserted/Negated — Denote the last fetched instruction or the number of instructions that were flushed from the instruction queue. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details.

Timing Comments Assertion/Negation — Transitions may occur every clock cycle. This signal is not synchronous with bus cycles. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information on these signals.

2.5.4.5 Instruction Flush Count (VFLS[0:1])

Output only
Module: Development support

State Meaning Asserted/Negated — Denote the number of instructions that are flushed from the history buffer during the current clock cycle. These signals also provide the freeze indication. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details.

Timing Comments Assertion/Negation — Transitions may occur every clock cycle. This signal is not synchronous with bus cycles. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information on these signals.

2.5.4.6 Watchpoints (WP[0:5])

Output only
Module: Development support

State Meaning Asserted — Indicate that a watchpoint event has occurred on the I-bus (WP[0:3]) or L-bus (WP[4:5]).

Negated — Indicate that no watchpoint event has occurred.

Timing Comments Assertion/Negation — Transitions may occur every clock cycle. This signal is not synchronous with bus cycles. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information on these signals.

2.5.5 Chip-Select Signals

2.5.5.1 Chip Select for System Boot Memory ($\overline{\text{CSBOOT}}$)

Input only
Module: Chip selects

State Meaning Asserted — Indicates the boot memory device is being selected. In systems that have no external boot device, this pin can be configured as a write enable or output enable of an external memory device. At power up, this pin defaults as a chip enable of the boot device.

Negated — Indicates the boot device is not being selected.

Timing Comments Assertion/Negation — This is an address phase signal when used as chip enable of the boot device, or a data phase signal when used as output enable or write enable of an external memory device. When this signal is a chip enable, assertion may be delayed from the assertion of $\overline{TS}$.

2.5.5.2 Chip Selects for External Memory ($\overline{CS[0:11]}$)

Output only
Module: Chip selects

State Meaning Asserted — Indicates that the memory region for which the chip select is programmed is being accessed. $\overline{CS[1:5]}$ can be programmed as chip enables, output enables, or write enables. $\overline{CS0}$ and $\overline{CS[6:11]}$ can be programmed as output enables or write enables.

Negated — Indicates that the memory region for which the chip select is programmed is not being accessed.

Timing Comments Assertion/Negation — These are address phase signals when used as chip enables ($\overline{CS[1:5]}$ only), or data phase signals when used as output enables or write enables. When these signals are chip enables, assertion may be delayed from the assertion of $\overline{TS}$.

2.5.6 Clock Signals

2.5.6.1 Clock Output (CLKOUT)

Output only
Module: Clocks

State Meaning Asserted/Negated — Provides a clock which runs continuously. All signals driven on the E-bus must be synchronized to the rising edge of this clock.

2.5.6.2 Engineering Clock Output (ECROUT)

Output only
Module: Clocks

State Meaning Asserted/Negated — Provides a buffered clock reference output with a frequency equal to the crystal oscillator frequency, taken from the PLL feedback signal.

2.5.6.3 Crystal Oscillator Connections (EXTAL, XTAL)

Input, Output
Module: EBI

State Meaning Connections for the external crystal to the internal oscillator circuit. An external oscillator should serve as input to the EXTAL pin, when used.

2.5.6.4 External Filter Capacitor Pins (XFCP, XFCN)

Input only
Module: EBI

State Meaning Used to add an external capacitor to the filter circuit of the phase-locked loop.

2.5.6.5 Clock Mode (MODCLK)

Input only
Module: EBI

Reset Operation During reset, this signal and V_{DDSN} select the source of the system clock. Refer to 5.8.3 Configuration During Reset for details.

2.5.6.6 Phase-Locked Loop Lock Signal (PLLL)

Output only
Module: Clocks

State Meaning Asserted — Indicates that the phase-locked loop is locked.

Negated — Indicates that the phase-locked loop is not locked.

2.5.6.7 Power-Down Wake-Up (PDWU)

Output only
Module: EBI

State Meaning Asserted — Can be used as power-down wakeup to external power-on reset circuit, or assertion can signal other events depending on system requirements. PDWU is asserted when bit 0 of the decrementer register changes from zero to one and can also be asserted by software. See the

RCPU Reference Manual (RCPURM/AD) for details on decrementer exceptions.

Negated — (By software) indicates the event causing assertion of PDWU is not or is no longer occurring.

Timing Comments Negation — Does not occur until at least one decrementer clock following assertion.

2.5.7 Reset Signals

The $\overline{\text{RESET}}$ and $\overline{\text{RESETOUT}}$ signals are used while the part is being placed into or coming out of reset. Refer to 5.8 Reset Operation for more details on these pins.

2.5.7.1 Reset ($\overline{\text{RESET}}$)

Input only
Module: Reset

State Meaning Asserted — Indicates that devices on the bus must reset.

Negated — Indicates normal operation.

Timing Comments For timing information, refer to 5.8 Reset Operation.

2.5.7.2 Reset Output ($\overline{\text{RESETOUT}}$)

Output only
Module: Reset

State Meaning Asserted — (During reset) instructs all devices monitoring this signal to reset all parts within themselves that can be reset by software. Assertion indicates that the MCU is in reset.

Negated — Indicates normal operation.

Timing Comments For timing information, refer to 5.8 Reset Operation.

2.5.8 SIU General-Purpose Input/Output Signals

Many of the pins associated with the SIU can be used for more than one function. The primary function of these pins is to provide an external bus interface. When not used for their primary function, many of these pins can be used for digital I/O. Refer to **5.9 General-Purpose I/O** for more information on these signals.

2.5.8.1 Ports A and B (PA[0:7], PB[0:7])

Output only
Module: Ports

State Meaning Asserted/Negated — Indicates the logic level of the data being transmitted. Port A and port B share a data register (PORTA/PORTB) and pin assignment register (PAPAR/PBPAR).

Timing Comments Assertion/Negation — Accesses to these ports require three clock cycles, the same as for external accesses to port replacement logic if a port replacement unit (PRU) is used.

2.5.8.2 Ports I, J, K, and L (PI[0:7], PJ[0:7], PK[0:7], PL[2:7]

Input/Output
Module: Ports

State Meaning Asserted/Negated — Indicates the logic level of the data being transmitted. Ports I, J, K, and L share a data register (PORTI, PORTJ, PORTK, PORTL), data direction register (DDRI, DDRJ, DDRK, DDRL), and pin assignment register (PIPAR, PJPAR, PKPAR, PLPAR).

Timing Comments Assertion/Negation — Accesses to these ports require three clock cycles, the same as for external accesses to port replacement logic if a port replacement unit (PRU) is used.

2.5.8.3 Port M (PM[3:7])

Input/Output
Module: EBI

State Meaning Asserted/Negated — Indicates the logic level of the data being transmitted.

Timing Comments Assertion/Negation — Accesses to port M require two clock cycles.

2.5.9 Interrupts and Port Q Signals

The MPC509 contains seven external interrupt pins. These pins are grouped into a general-purpose port (port Q). When not used as interrupt inputs, any of these pins can be used for digital input or output. Refer to SECTION 6 PERIPHERAL CONTROL UNIT for more information on these pins.

2.5.9.1 Interrupt Requests ($\overline{\text{IRQ}}$[0:6])

Input only
Module: EBI

State Meaning Asserted — Indicates an external interrupt is being requested with a request level corresponding to the $\overline{\text{IRQ}}$ number of the pin.

Negated — Indicates no external interrupt when the indicated level is being requested.

2.5.9.2 Port Q (PQ[0:6])

Input/Output
Module: PCU

State Meaning Asserted/Negated — Indicates the logic level of the data being transmitted.

Timing Comments Assertion/Negation — Accesses to port Q require two clock cycles.

2.5.10 JTAG Interface Signals

Refer to SECTION 9 IEEE 1149.1-COMPLIANT INTERFACE for more information on these pins.

2.5.10.1 Test Data Input (TDI)

Input only
Module: JTAG

State Meaning Asserted/Negated — Represents the value of the test data input.

Timing Comments Sampled on the rising edge of TCK.

2.5.10.2 Test Data Output (TDO)

Output only
Module: JTAG

State Meaning Asserted/Negated — Represents the value of the test data output.

Timing Comments Changes on the falling edge of TCK.

2.5.10.3 Test Mode Select (TMS)

Input only
Module: JTAG

State Meaning Asserted/Negated — Sequences the test controller's state machine.

Timing Comments Sampled on the rising edge of TCK.

2.5.10.4 Test Clock (TCK)

Input only
Module: JTAG

State Meaning Test clock input to synchronize the test logic.

2.5.10.5 Test Reset ($\overline{\text{TRST}}$)

Input only
Module: JTAG

State Meaning	Asserted — Signals TAP controller to reset itself.
Timing Comments	Asynchronous.

SECTION 3
CENTRAL PROCESSING UNIT

The PowerPC-based RISC processor (RCPU) used in the MPC509 integrates four execution units: an integer unit (IU), a load/store unit (LSU), a branch processing unit (BPU), and a floating-point unit (FPU). The use of simple instructions with rapid execution times yields high efficiency and throughput for MPC509-based systems.

Most integer instructions execute in one clock cycle. The FPU includes single- and double-precision multiply-add instructions. Instructions can complete out of order for increased performance; however, the processor makes execution appear sequential.

This section provides an overview of the RCPU. For a more detailed description, see the *RCPU Reference Manual* (RCPURM/AD).

3.1 RCPU Features

- High-performance microprocessor
  - — Single clock-cycle execution for many instructions
- Four independent execution units and two register files
  - — Independent LSU for load and store operations
  - — BPU featuring static branch prediction
  - — A 32-bit IU
  - — Fully IEEE 754-compliant FPU for both single- and double-precision operations
  - — Thirty-two general-purpose registers (GPRs) for integer operands
  - — Thirty-two floating-point registers (FPRs) for single- or double-precision operands
- Facilities for enhanced system performance
  - — Programmable big- and little-endian byte ordering
  - — Atomic memory references
- In-system testability and debugging features through boundary-scan capability
- High instruction and data throughput
  - — Condition register (CR) look-ahead operations performed by BPU
  - — Branch-folding capability during execution (zero-cycle branch execution time)
  - — Programmable static branch prediction on unresolved conditional branches
  - — A prefetch queue that can hold up to four instructions, providing look-ahead capability
  - — Interlocked pipelines with feed-forwarding that control data dependencies in hardware
  - — 4-Kbyte instruction cache: two-way set-associative, LRU replacement algorithm

3.2 RCPU Block Diagram

Figure 3-1 is a block diagram of the RCPU.

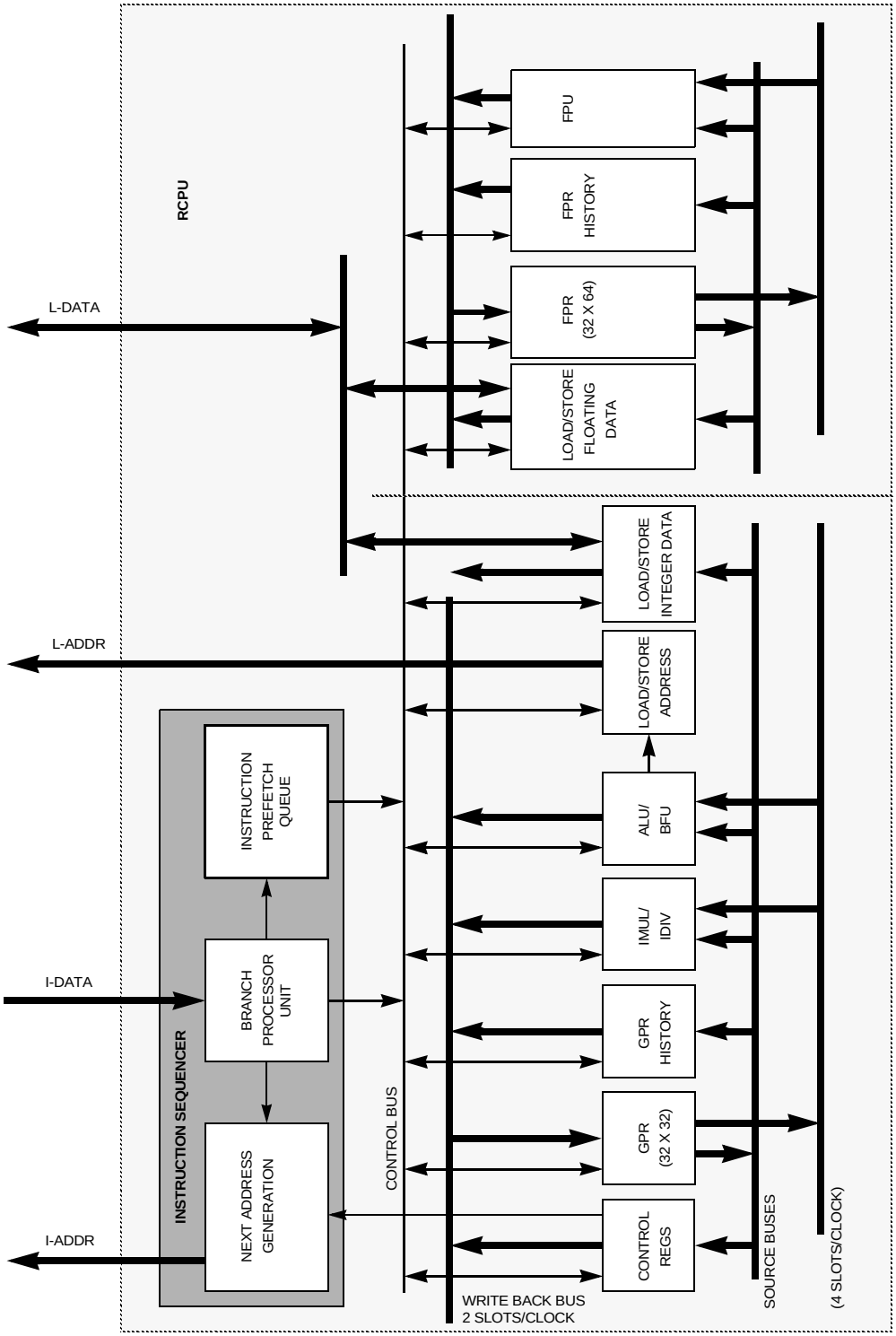


Figure 3-1 RCPU Block Diagram

3.3 Instruction Sequencer

The instruction sequencer (see **Figure 3-2**) provides centralized control over data flow between execution units and register files. The sequencer implements the basic instruction pipeline, fetches instructions from the memory system, issues them to available execution units, and maintains a state history so it can back the machine up in the event of an exception.

The sequencer fetches the instructions from the instruction cache into the instruction pre-fetch queue. The BPU extracts branch instructions from the pre-fetch queue and uses static branch prediction on unresolved conditional branches to allow the instruction unit to fetch instructions from a predicted target instruction stream while a conditional branch is evaluated. The BPU folds out branch instructions for unconditional branches or conditional branches unaffected by instructions in the execution stage.

Instructions issued beyond a predicted branch do not complete execution until the branch is resolved, preserving the programming model of sequential execution. If branch prediction is incorrect, the instruction unit flushes all predicted path instructions, and instructions are issued from the correct path.

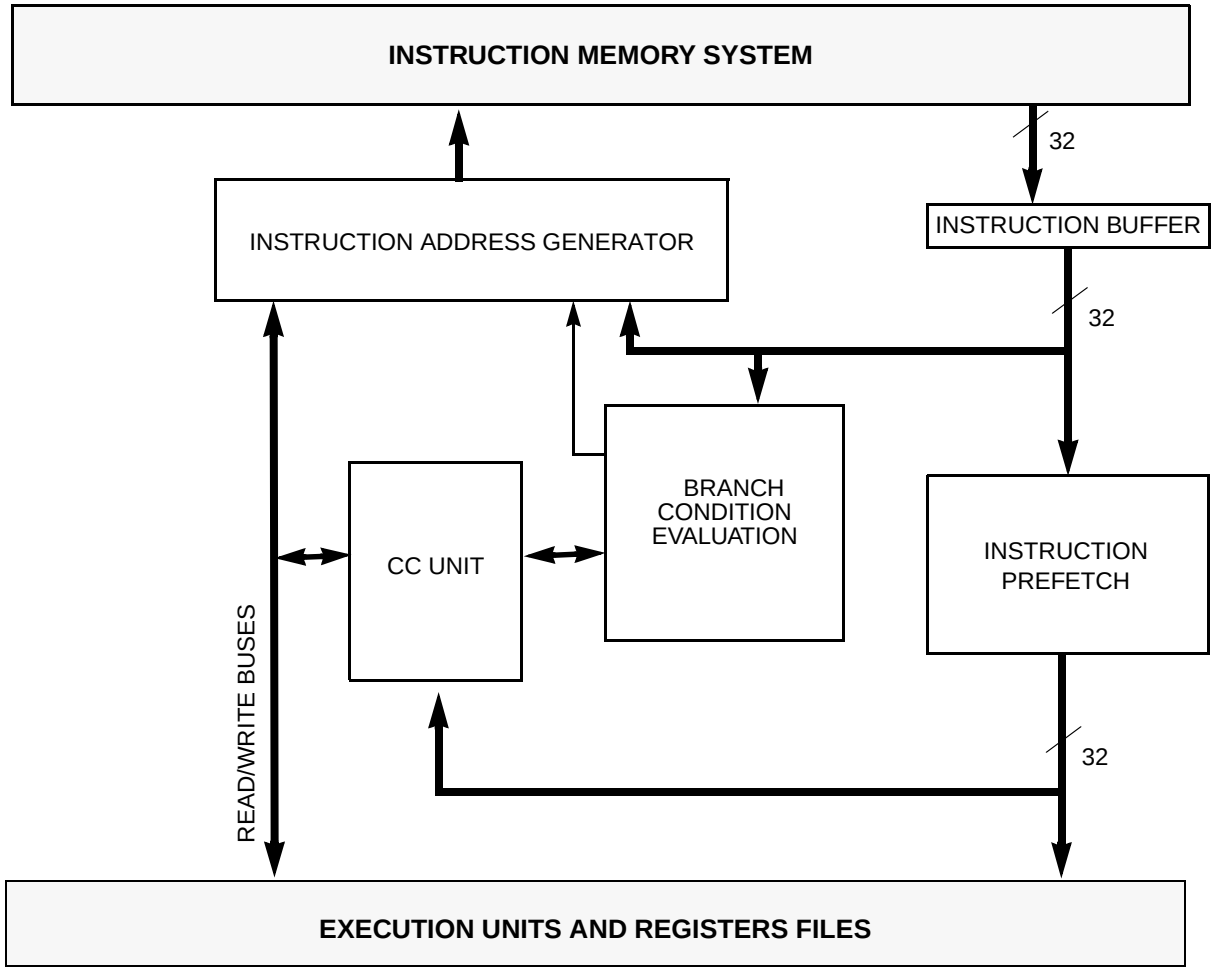


Figure 3-2 Sequencer Data Path

3.4 Independent Execution Units

The PowerPC architecture supports independent floating-point, integer, load-store, and branch processing execution units, making it possible to implement advanced features such as look-ahead operations. For example, since branch instructions do not depend on GPRs or FPRs, branches can often be resolved early, eliminating stalls caused by taken branches.

Table 3-1 summarizes the RCPU execution units.

Table 3-1 RCPU Execution Units

Unit	Description
Branch processing unit (BPU)	Includes the implementation of all branch instructions.
Load/store unit (LSU)	Includes implementation of all load and store instructions, whether defined as part of the integer processor or the floating-point processor.
Integer unit (IU)	Includes implementation of all integer instructions except load-store instructions. This module includes the GPRs (including GPR history and scoreboard) and the following subunits: The IMUL-IDIV includes the implementation of the integer multiply and divide instructions. The ALU-BFU includes implementation of all integer logic, add and subtract instructions, and bit field instructions.
Floating-point unit (FPU)	Includes the FPRs (including FPR history and scoreboard) and the implementation of all floating-point instructions except load and store floating-point instructions.

The following sections describe the execution units in greater detail.

3.4.1 Branch Processing Unit (BPU)

The BPU, located within the instruction sequencer, performs condition register look-ahead operations on conditional branches. The BPU looks through the instruction queue for a conditional branch instruction and attempts to resolve it early, achieving the effect of a zero-cycle branch in many cases.

The BPU uses a bit in the instruction encoding to predict the direction of the conditional branch. Therefore, when an unresolved conditional branch instruction is encountered, the processor prefetches instructions from the predicted target stream until the conditional branch is resolved.

The BPU contains an adder to compute branch target addresses and three special-purpose, user-accessible registers: the link register (LR), the count register (CTR), and the condition register (CR). The BPU calculates the return pointer for subroutine calls and saves it into the LR. The LR also contains the branch target address for the branch conditional to link register (**bclr***x*) instruction. The CTR contains the branch target address for the branch conditional to count register (**bcctr***x*) instruction. The contents of the LR and CTR can be copied to or from any GPR. Because the BPU uses dedicated registers rather than general-purpose or floating-point registers, execution of branch instructions is independent from execution of integer and floating-point instructions.

3.4.2 Integer Unit (IU)

The IU executes all integer processor instructions, except the integer storage access instructions, which are implemented by the load/store unit. The IU contains the following subunits:

- The IMUL-IDIV unit includes the implementation of the integer multiply and divide instructions.

- The ALU-BFU unit includes the implementation of all integer logic, add and subtract, and bit field instructions.

The IU also includes the integer exception register (XER) and the general-purpose register file.

IMUL-IDIV and ALU-BFU are implemented as separate execution units. The ALU-BFU unit can execute one instruction per clock cycle. IMUL-IDIV instructions require multiple clock cycles to execute. IMUL-IDIV is pipelined for multiply instructions, so that consecutive multiply instructions can be issued on consecutive clock cycles. Divide instructions are not pipelined; an integer divide instruction preceded or followed by an integer divide or multiply instruction results in a stall in the processor pipeline. Note that since IMUL-IDIV and ALU-BFU are implemented as separate execution units, an integer divide instruction preceded or followed by an ALU-BFU instruction does not cause a delay in the pipeline.

3.4.3 Load/Store Unit (LSU)

The load-store unit handles all data transfer between the general-purpose and floating-point register files and the internal load/store bus (L-bus). The load/store unit is implemented as an independent execution unit so that stalls in the memory pipeline do not cause the master instruction pipeline to stall (unless there is a data dependency). The unit is fully pipelined so that memory instructions of any size may be issued on back-to-back cycles.

There is a 32-bit wide data path between the load/store unit and the general-purpose register file and a 64-bit-wide data path between the load/store unit and the floating-point register file. Single-word accesses to the internal on-chip data RAM require one clock, resulting in two clocks latency. Double-word accesses require two clocks, resulting in three clocks latency. Since the L-bus is 32 bits wide, double-word transfers require two bus accesses. The load/store unit performs zero-fill for byte and half-word transfers and sign extension for half-word transfers.

Addresses are formed by adding the source one register operand specified by the instruction (or zero) to either a source two register operand or to a 16-bit, immediate value embedded in the instruction.

3.4.4 Floating-Point Unit (FPU)

The FPU contains a double-precision multiply array, the floating-point status and control register (FPSCR), and the FPRs. The multiply-add array allows the MPC509 to efficiently implement floating-point operations such as multiply, multiply-add, and divide.

The MPC509 depends on a software envelope to fully implement the IEEE floating-point specification. Overflows, underflows, NaNs, and denormalized numbers cause floating-point assist exceptions that invoke a software routine to deliver (with hardware assistance) the correct IEEE result.

To accelerate time-critical operations and make them more deterministic, the MPC509 provides a mode of operation that avoids invoking the software envelope and attempts

to deliver results in hardware that are adequate for most applications, if not in strict conformance with IEEE standards. In this mode, denormalized numbers, NaNs, and IEEE invalid operations are treated as legitimate, returning default results rather than causing floating-point assist exceptions.

3.5 Levels of the PowerPC Architecture

The PowerPC architecture consists of three layers. Adherence to the PowerPC architecture can be measured in terms of which of the following levels of the architecture are implemented:

- PowerPC user instruction set architecture (UISA) — Defines the base user-level instruction set, user-level registers, data types, floating-point exception model, memory models for a uniprocessor environment, and programming model for a uniprocessor environment.
- PowerPC virtual environment architecture (VEA) — Describes the memory model for a multiprocessor environment, defines cache control instructions, and describes other aspects of virtual environments. Implementations that conform to the VEA also adhere to the UISA, but may not necessarily adhere to the OEA.
- PowerPC operating environment architecture (OEA) — Defines the memory management model, supervisor-level registers, synchronization requirements, and the exception model. Implementations that conform to the OEA also adhere to the UISA and the VEA.

3.6 RCPU Programming Model

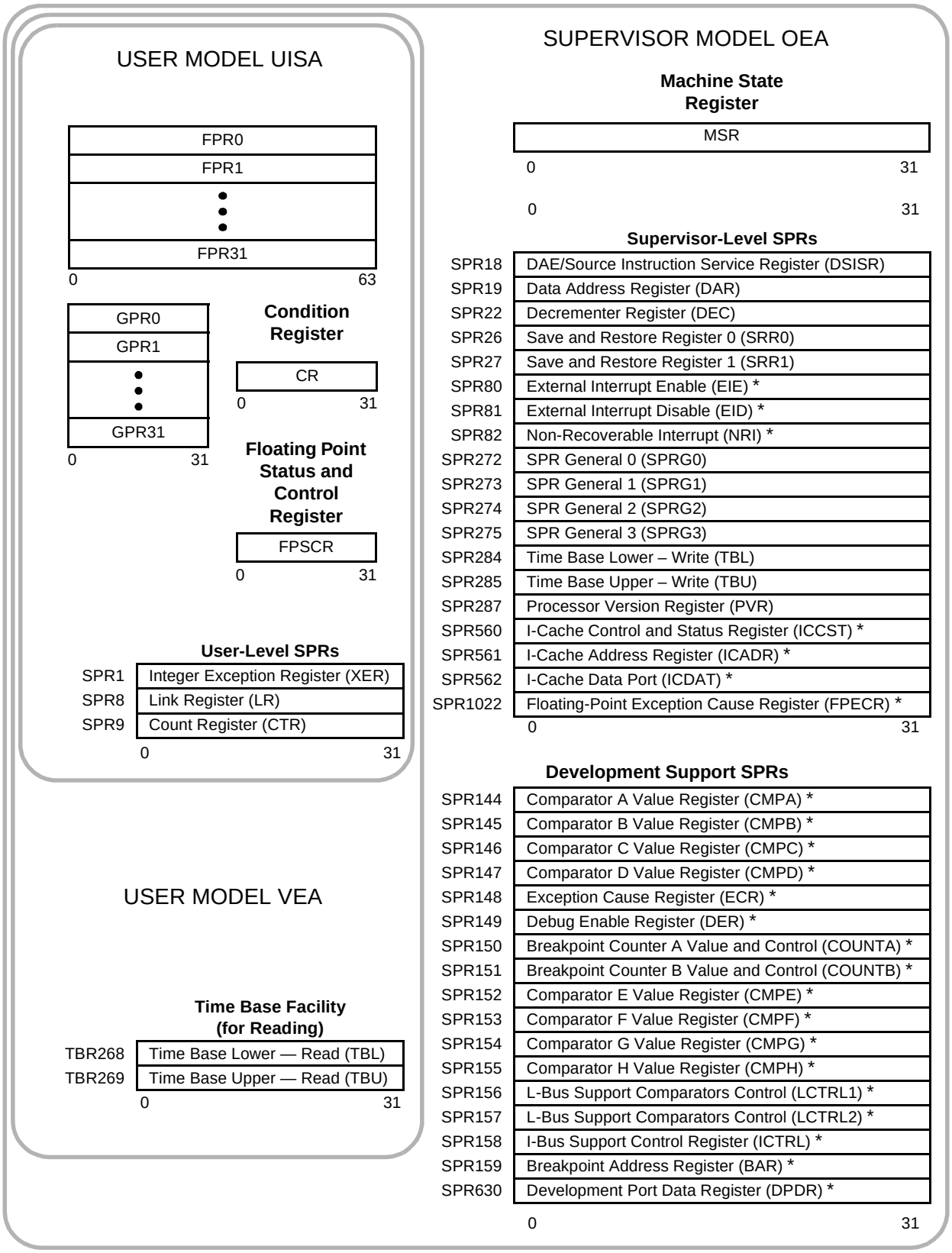
The PowerPC architecture defines register-to-register operations for most computational instructions. Source operands for these instructions are accessed from the registers or are provided as immediate values embedded in the instruction opcode. The three-register instruction format allows specification of a target register distinct from the two source operands. Load and store instructions transfer data between memory and on-chip registers.

PowerPC processors have two levels of privilege: supervisor mode of operation (typically used by the operating environment) and user mode of operation (used by the application software). The programming models incorporate 32 GPRs, 32 FPRs, special-purpose registers (SPRs), and several miscellaneous registers.

Supervisor-level access is provided through the processor's exception mechanism. That is, when an exception is taken (either due to an error or problem that needs to be serviced, or deliberately through the use of a trap instruction), the processor begins operating in supervisor mode. The level of access is indicated by the privilege-level (PR) bit in the machine state register (MSR).

Figure 3-3 shows the user-level and supervisor-level RCPU programming models and also illustrates the three levels of the PowerPC architecture. The numbers to the left of the SPRs indicate the decimal number that is used in the syntax of the instruction operands to access the register.

Note that registers such as the general-purpose registers (GPRs) and floating-point registers (FPRs) are accessed through operands that are part of the instructions. Access to registers can be explicit (that is, through the use of specific instructions for that purpose such as move to special-purpose register (**mtspr**) and move from special-purpose register (**mfspr**) instructions) or implicitly as the part of the execution of an instruction. Some registers are accessed both explicitly and implicitly.


USER MODEL UISA
FPR0
FPR1
FPR31
0
63
GPR0
GPR1
GPR31
0
31
Condition Register
CR
0
31
Floating Point Status and Control Register
FPSCR
0
31
User-Level SPRs
SPR1 Integer Exception Register (XER)
SPR8 Link Register (LR)
SPR9 Count Register (CTR)
0
31
USER MODEL VEA
Time Base Facility (for Reading)
TBR268 Time Base Lower — Read (TBL)
TBR269 Time Base Upper — Read (TBU)
0
31
SUPERVISOR MODEL OEA
Machine State Register
MSR
0
31
0
31
Supervisor-Level SPRs
SPR18 DAE/Source Instruction Service Register (DSISR)
SPR19 Data Address Register (DAR)
SPR22 Decrementer Register (DEC)
SPR26 Save and Restore Register 0 (SRR0)
SPR27 Save and Restore Register 1 (SRR1)
SPR80 External Interrupt Enable (EIE) *
SPR81 External Interrupt Disable (EID) *
SPR82 Non-Recoverable Interrupt (NRI) *
SPR272 SPR General 0 (SPRG0)
SPR273 SPR General 1 (SPRG1)
SPR274 SPR General 2 (SPRG2)
SPR275 SPR General 3 (SPRG3)
SPR284 Time Base Lower – Write (TBL)
SPR285 Time Base Upper – Write (TBU)
SPR287 Processor Version Register (PVR)
SPR560 I-Cache Control and Status Register (ICCST) *
SPR561 I-Cache Address Register (ICADR) *
SPR562 I-Cache Data Port (ICDAT) *
SPR1022 Floating-Point Exception Cause Register (FPECR) *
0
31
Development Support SPRs
SPR144 Comparator A Value Register (CMPA) *
SPR145 Comparator B Value Register (CMPB) *
SPR146 Comparator C Value Register (CMPC) *
SPR147 Comparator D Value Register (CMPD) *
SPR148 Exception Cause Register (ECR) *
SPR149 Debug Enable Register (DER) *
SPR150 Breakpoint Counter A Value and Control (COUNTA) *
SPR151 Breakpoint Counter B Value and Control (COUNTB) *
SPR152 Comparator E Value Register (CMPE) *
SPR153 Comparator F Value Register (CMPF) *
SPR154 Comparator G Value Register (CMPG) *
SPR155 Comparator H Value Register (CMPH) *
SPR156 L-Bus Support Comparators Control (LCTRL1) *
SPR157 L-Bus Support Comparators Control (LCTRL2) *
SPR158 I-Bus Support Control Register (ICTRL) *
SPR159 Breakpoint Address Register (BAR) *
SPR630 Development Port Data Register (DPDR) *
0
31

* Specific to the RCPU implementation of the PowerPC Architecture

RMCU CPU REG MA

Figure 3-3 RCPU Programming Model

Where not otherwise noted, reserved fields in registers are ignored when written to and return zero when read. An exception to this rule is XER[16:23]. These bits are set to the value written to them and return that value when read.

3.7 PowerPC UISA Register Set

The PowerPC UISA registers can be accessed by either user- or supervisor-level instructions. The general-purpose registers and floating-point registers are accessed through instruction operands.

3.7.1 General-Purpose Registers (GPRs)

Integer data is manipulated in the integer unit's thirty-two 32-bit GPRs, shown below. These registers are accessed as source and destination registers through operands in the instruction syntax.

GPRs — General-Purpose Registers

0	31
GPR0	
GPR1	
. . .	
. . .	
GPR31	

RESET: UNCHANGED

3.7.2 Floating-Point Registers (FPRs)

The PowerPC architecture provides thirty-two 64-bit FPRs. These registers are accessed as source and destination registers through operands in floating-point instructions. Each FPR supports the double-precision, floating-point format. Every instruction that interprets the contents of an FPR as a floating-point value uses the double-precision floating-point format for this interpretation. That is, all floating-point numbers are stored in double-precision format.

All floating-point arithmetic instructions operate on data located in FPRs and, with the exception of the compare instructions (which update the CR), place the result into an FPR. Information about the status of floating-point operations is placed into the floating-point status and control register (FPSCR) and in some cases, into the CR, after the completion of the operation's writeback stage. For information on how the CR is affected by floating-point operations, see 3.7.4 Condition Register (CR).

FPRs — Floating-Point Registers

0	63
FPR0	
FPR1	
. . .	
. . .	
FPR31	

RESET: UNCHANGED

3.7.3 Floating-Point Status and Control Register (FPSCR)

The FPSCR controls the handling of floating-point exceptions and records status resulting from the floating-point operations. FPSCR[0:23] are status bits, while FPSCR[24:31] are control bits.

FPSCR[0:12] and FPSCR[21:23] are floating-point exception condition bits. These bits are sticky, except for the floating-point enabled exception summary (FEX) and floating-point invalid operation exception summary (VX). Once set, sticky bits remain set until they are cleared by an **mcrfs**, **mtfsfi**, **mtfsf**, or **mtfsb0** instruction.

Table 3-2 summarizes which bits in the FPSCR are sticky status bits, which are normal status bits, and which are control bits.

Table 3-2 FPSCR Bit Categories

Bits	Type
[0], [3:12], [21:23]	Status, sticky
[1:2], [13:20]	Status, not sticky
[24:31]	Control

FEX and VX are the logical ORs of other FPSCR bits. Therefore these two bits are not listed among the FPSCR bits directly affected by the various instructions.

FPSCR — Floating-Point Status and Control Register

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FX	FEX	VX	OX	UX	ZX	XX	VXS-NAN	VXISI	VXIDI	VXZDZ	VXIMZ	VXVC	FR	FI	FPRF0

RESET: UNCHANGED

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FPRF[1:4]				0	VX-SOFT	VX-SQRT	VXCVI	VE	OE	UE	ZE	XE	NI	RN	

RESET: UNCHANGED

A listing of FPSCR bit settings is shown in **Table 3-3**.

Table 3-3 FPSCR Bit Settings

Bit(s)	Name	Description
0	FX	Floating-point exception summary. Every floating-point instruction implicitly sets FPSCR[FX] if that instruction causes any of the floating-point exception bits in the FPSCR to change from zero to one. The **mcrfs** instruction implicitly clears FPSCR[FX] if the FPSCR field containing FPSCR[FX] is copied. The **mtfsf**, **mtfsfi**, **mtfsb0**, and **mtfsb1** instructions can set or clear FPSCR[FX] explicitly. This is a sticky bit.
1	FEX	Floating-point enabled exception summary. This bit signals the occurrence of any of the enabled exception conditions. It is the logical OR of all the floating-point exception bits masked with their respective enable bits. The **mcrfs** instruction implicitly clears FPSCR[FEX] if the result of the logical OR described above becomes zero. The **mtfsf**, **mtfsfi**, **mtfsb0**, and **mtfsb1** instructions cannot set or clear FPSCR[FEX] explicitly. This is not a sticky bit.
2	VX	Floating-point invalid operation exception summary. This bit signals the occurrence of any invalid operation exception. It is the logical OR of all of the invalid operation exceptions. The **mcrfs** instruction implicitly clears FPSCR[VX] if the result of the logical OR described above becomes zero. The **mtfsf**, **mtfsfi**, **mtfsb0**, and **mtfsb1** instructions cannot set or clear FPSCR[VX] explicitly. This is not a sticky bit.
3	OX	Floating-point overflow exception. This is a sticky bit.
4	UX	Floating-point underflow exception. This is a sticky bit.
5	ZX	Floating-point zero divide exception. This is a sticky bit.
6	XX	Floating-point inexact exception. This is a sticky bit.
7	VXSNAN	Floating-point invalid operation exception for SNaN. This is a sticky bit.
8	VXISI	Floating-point invalid operation exception for ×-×. This is a sticky bit.
9	VXIDI	Floating-point invalid operation exception for ×/×. This is a sticky bit.
10	VXZDZ	Floating-point invalid operation exception for 0/0. This is a sticky bit.
11	VXIMZ	Floating-point invalid operation exception for ×*0. This is a sticky bit.
12	VXVC	Floating-point invalid operation exception for invalid compare. This is a sticky bit.
13	FR	Floating-point fraction rounded. The last floating-point instruction that potentially rounded the intermediate result incremented the fraction. This bit is not sticky.
14	FI	Floating-point fraction inexact. The last floating-point instruction that potentially rounded the intermediate result produced an inexact fraction or a disabled exponent overflow. This bit is not sticky.
15:19	FPRF	Floating-point result flags. This field is based on the value placed into the target register even if that value is undefined. Refer to **Table 3-4** for specific bit settings. 15 Floating-point result class descriptor (C). Floating-point instructions other than the compare instructions may set this bit with the FPCC bits, to indicate the class of the result. 16:19 Floating-point condition code (FPCC). Floating-point compare instructions always set one of the FPCC bits to one and the other three FPCC bits to zero. Other floating-point instructions may set the FPCC bits with the C bit, to indicate the class of the result. Note that in this case the high-order three bits of the FPCC retain their relational significance indicating that the value is less than, greater than, or equal to zero. 16 Floating-point less than or negative (FL or <) 17 Floating-point greater than or positive (FG or >) 18 Floating-point equal or zero (FE or =) 19 Floating-point unordered or NaN (FU or ?)
20	—	Reserved

Table 3-3 FPSCR Bit Settings (Continued)

Bit(s)	Name	Description
21	VXSOFT	Floating-point invalid operation exception for software request. This bit can be altered only by the **mcrfs**, **mtfsfi**, **mtfsf**, **mtfsb0**, or **mtfsb1** instructions. The purpose of VXSOFT is to allow software to cause an invalid operation condition for a condition that is not necessarily associated with the execution of a floating-point instruction. For example, it might be set by a program that computes a square root if the source operand is negative. This is a sticky bit.
22	VXSQRT	Floating-point invalid operation exception for invalid square root. This is a sticky bit. This guarantees that software can simulate **fsqrt** and **frsqrte**, and to provide a consistent interface to handle exceptions caused by square-root operations.
23	VXCVI	Floating-point invalid operation exception for invalid integer convert. This is a sticky bit.
24	VE	Floating-point invalid operation exception enable.
25	OE	Floating-point overflow exception enable.
26	UE	Floating-point underflow exception enable. This bit should not be used to determine whether denormalization should be performed on floating-point stores.
27	ZE	Floating-point zero divide exception enable.
28	XE	Floating-point inexact exception enable.
29	NI	Non-IEEE mode bit.
30:31	RN	Floating-point rounding control. 00 = Round to nearest 01 = Round toward zero 10 = Round toward +infinity 11 = Round toward –infinity

Table 3-4 illustrates the floating-point result flags that correspond to FPSCR[15:19].

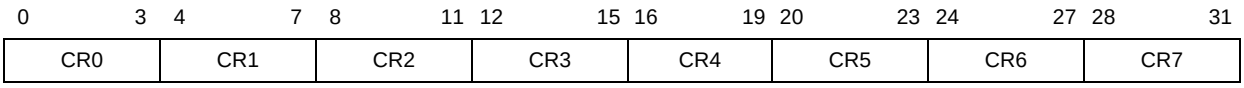
Table 3-4 Floating-Point Result Flags in FPSCR

Result Flags (Bits 15:19) C<>=?	Result Value Class
10001	Quiet NaN
01001	– Infinity
01000	– Normalized number
11000	– Denormalized number
10010	– Zero
00010	+ Zero
10100	+ Denormalized number
00100	+ Normalized number
00101	+ Infinity

3.7.4 Condition Register (CR)

The condition register (CR) is a 32-bit register that reflects the result of certain operations and provides a mechanism for testing and branching. The bits in the CR are grouped into eight 4-bit fields, CR0 to CR7.

CR — Condition Register



RESET: UNCHANGED

The CR fields can be set in the following ways:

- Specified fields of the CR can be set by a move instruction (**mtcrf**) to the CR from a GPR.
- Specified fields of the CR can be moved from one CR*x* field to another with the **mcrf** instruction.
- A specified field of the CR can be set by a move instruction (**mcrfs**) to the CR from the FPSCR.
- A specified field of the CR can be set by a move instruction (**mcrxr**) to the CR from the XER.
- Condition register logical instructions can be used to perform logical operations on specified bits in the condition register.
- CR0 can be the implicit result of an integer operation.
- CR1 can be the implicit result of a floating-point operation.
- A specified CR field can be the explicit result of either an integer or floating-point compare instruction.

Instructions are provided to test individual CR bits.

3.7.4.1 Condition Register CR0 Field Definition

In most integer instructions, when the CR is set to reflect the result of the operation (that is, when Rc = 1), and for **addic.**, **andi.**, and **andis.**, the first three bits of CR0 are set by an algebraic comparison of the result to zero; the fourth bit of CR0 is copied from XER[SO]. For integer instructions, CR[0:3] are set to reflect the result as a signed quantity. The result as an unsigned quantity or a bit string can be deduced from the EQ bit.

The CR0 bits are interpreted as shown in **Table 3-5**. If any portion of the result (the 32-bit value placed into the destination register) is undefined, the value placed in the first three bits of CR0 is undefined.

Table 3-5 Bit Settings for CR0 Field of CR

CR0 Bit	Description
0	Negative (LT) — This bit is set when the result is negative.
1	Positive (GT) — This bit is set when the result is positive (and not zero).
2	Zero (EQ) — This bit is set when the result is zero.
3	Summary overflow (SO) — This is a copy of the final state of XER[SO] at the completion of the instruction.

3.7.4.2 Condition Register CR1 Field Definition

In all floating-point instructions when the CR is set to reflect the result of the operation (that is, when Rc = 1), the CR1 field (bits 4 to 7 of the CR) is copied from FPSCR[0:3]

to indicate the floating-point exception status. For more information about the FPSCR, see 3.7.3 Floating-Point Status and Control Register (FPSCR). The bit settings for the CR1 field are shown in **Table 3-6**.

Table 3-6 Bit Settings for CR1 Field of CR

CR1 Bit	Description
0	Floating-point exception (FX) — This is a copy of the final state of FPSCR[FX] at the completion of the instruction.
1	Floating-point enabled exception (FEX) — This is a copy of the final state of FPSCR[FEX] at the completion of the instruction.
2	Floating-point invalid exception (VX) — This is a copy of the final state of FPSCR[VX] at the completion of the instruction.
3	Floating-point overflow exception (OX) — This is a copy of the final state of FPSCR[OX] at the completion of the instruction.

3.7.4.3 Condition Register CR*n* Field — Compare Instruction

When a specified CR field is set by a compare instruction, the bits of the specified field are interpreted as shown in **Table 3-7**. A condition register field can also be accessed by the **mfcr**, **mcrf**, and **mtcrf** instructions.

Table 3-7 CR*n* Field Bit Settings for Compare Instructions

CR*n* Bit[1]	Description
0	Less than, floating-point less than (LT, FL). For integer compare instructions, (**r**A) < SIMM, UIMM, or (**r**B) (algebraic comparison) or (**r**A) SIMM, UIMM, or (**r**B) (logical comparison). For floating-point compare instructions, (**fr**A) < (**fr**B).
1	Greater than, floating-point greater than (GT, FG). For integer compare instructions, (**r**A) > SIMM, UIMM, or (**r**B) (algebraic comparison) or (**r**A) SIMM, UIMM, or (**r**B) (logical comparison). For floating-point compare instructions, (**fr**A) > (**fr**B).
2	Equal, floating-point equal (EQ, FE). For integer compare instructions, (**r**A) = SIMM, UIMM, or (**r**B). For floating-point compare instructions, (**fr**A) = (**fr**B).
3	Summary overflow, floating-point unordered (SO, FU). For integer compare instructions, this is a copy of the final state of XER[SO] at the completion of the instruction. For floating-point compare instructions, one or both of (**fr**A) and (**fr**B) is not a number (NaN).

NOTES:
1. Here, the bit indicates the bit number in any one of the four-bit subfields, CR0–CR7

3.7.5 Integer Exception Register (XER)

The integer exception register (XER) is a user-level, 32-bit register.

XER — Integer Exception Register **SPR 1**

0	1	2	3	24	25	26	27	28	29	30	31
SO	OV	CA	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		BYTES						

RESET: UNCHANGED

The bit definitions for XER, shown in **Table 3-8**, are based on the operation of an instruction considered as a whole, not on intermediate results. For example, the result of the subtract from carrying (**subfc***x*) instruction is specified as the sum of three values. This instruction sets bits in the XER based on the entire operation, not on an intermediate sum.

In most cases, reserved fields in registers are ignored when written to and return zero when read. However, XER[16:23] are set to the value written to them and return that value when read.

Table 3-8 Integer Exception Register Bit Definitions

Bit(s)	Name	Description
0	SO	Summary Overflow (SO) — The summary overflow bit is set whenever an instruction sets the overflow bit (OV) to indicate overflow and remains set until software clears it. It is not altered by compare instructions or other instructions that cannot overflow.
1	OV	Overflow (OV) — The overflow bit is set to indicate that an overflow has occurred during execution of an instruction. Integer and subtract instructions having OE = 1 set OV if the carry out of bit 0 is not equal to the carry out of bit 1, and clear it otherwise. The OV bit is not altered by compare instructions or other instructions that cannot overflow.
2	CA	Carry (CA) — In general, the carry bit is set to indicate that a carry out of bit 0 occurred during execution of an instruction. Add carrying, subtract from carrying, add extended, and subtract from extended instructions set CA to one if there is a carry out of bit 0, and clear it otherwise. The CA bit is not altered by compare instructions or other instructions that cannot carry, except that shift right algebraic instructions set the CA bit to indicate whether any ‘1’ bits have been shifted out of a negative quantity.
3:24	—	Reserved
25:31	BYTES	This field specifies the number of bytes to be transferred by a load string word indexed (**lswx**) or store string word indexed (**stswx**) instruction.

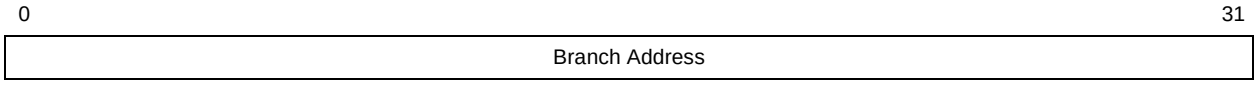
3.7.6 Link Register (LR)

The 32-bit link register supplies the branch target address for the branch conditional to link register (**bclr***x*) instruction, and can be used to hold the logical address of the instruction that follows a branch and link instruction.

Note that although the two least-significant bits can accept any values written to them, they are ignored when the LR is used as an address.

Both conditional and unconditional branch instructions include the option of placing the effective address of the instruction following the branch instruction in the LR. This is done regardless of whether the branch is taken.

LR — Link Register **SPR 8**

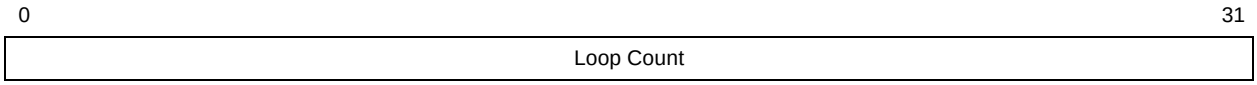


RESET: UNCHANGED

3.7.7 Count Register (CTR)

The count register (CTR) is a 32-bit register for holding a loop count that can be decremented during execution of branch instructions that contain an appropriately coded BO field. If the value in CTR is zero before being decremented, it is –1 afterward. The count register provides the branch target address for the branch conditional to count register (**bcctr***x*) instruction.

CTR — Count Register **SPR 9**



RESET: UNCHANGED

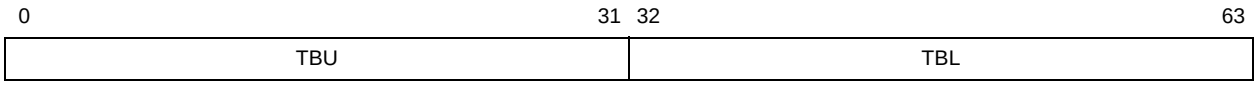
3.8 PowerPC VEA Register Set — Time Base

The PowerPC virtual environment architecture (VEA) defines registers in addition to those in the UISA register set. The PowerPC VEA register set can be accessed by all software (regardless of privilege level).

The PowerPC VEA includes the time base facility (TB), a 64-bit structure that contains a 64-bit unsigned integer that is incremented periodically. The frequency at which the counter is updated is implementation-dependent.

The TB consists of two 32-bit registers: time base upper (TBU) and time base lower (TBL). In the context of the VEA, user-level applications are permitted read-only access to the TB. The OEA defines supervisor-level access to the TB for writing values to the TB. Different SPR encodings are provided for reading and writing the time base.

TB — Time Base (Reading) **TBR 268, 269**



RESET: UNCHANGED

Table 3-9 Time Base Field Definitions

Bits	Name	Description
0:31	TBU	Time Base (Upper) — The high-order 32 bits of the time base
32:63	TBL	Time Base (Lower) — The low-order 32 bits of the time base

In 32-bit PowerPC implementations such as the RCPU, it is not possible to read the entire 64-bit time base in a single instruction. The **mftb** simplified mnemonic copies

the lower half of the time base register (TBL) to a GPR, and the **mftbu** simplified mnemonic copies the upper half of the time base (TBU) to a GPR.

3.9 PowerPC OEA Register Set

The PowerPC operating environment architecture (OEA) includes a number of SPRs and other registers that are accessible only by supervisor-level instructions. Some SPRs are RCPU-specific; some RCPU SPRs may not be implemented in other PowerPC processors, or may not be implemented in the same way.

3.9.1 Machine State Register (MSR)

The machine state register is a 32-bit register that defines the state of the processor. When an exception occurs, the current contents of the MSR are loaded into SRR1, and the MSR is updated to reflect the exception-processing machine state. The MSR can also be modified by the **mtmsr**, **sc**, and **rfi** instructions. It can be read by the **mfmsr** instruction.

MSR — Machine State Register

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED															ILE
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
EE	PR	FP	ME	FE0	SE	BE	FE1	0	IP	RESERVED				RI	LE
RESET:															
0	0	0	U	0	0	0	0	0	*	0	0	0	0	0	0

*Reset value of this bit depends on the value of the data bus reset configuration word.

Table 3-10 shows the bit definitions for the MSR.

Table 3-10 Machine State Register Bit Settings

Bit(s)	Name	Description
0:14	—	Reserved
15	ILE	Exception little endian mode. When an exception occurs, this bit is copied into MSR[LE] to select the endian mode for the context established by the exception. 0 = Processor runs in big endian mode during exception processing. 1 = Processor runs in little endian mode during exception processing.
16	EE	External interrupt enable 0 = The processor delays recognition of external interrupts and decrementer exception conditions. 1 = The processor is enabled to take an external interrupt or the decrementer exception. **Caution**: Be sure the EE bit is cleared before changing the masks of any on- or off-chip interrupt sources or before negating any interrupt sources.
17	PR	Privilege level 0 = The processor can execute both user- and supervisor-level instructions. 1 = The processor can only execute user-level instructions.

Table 3-10 Machine State Register Bit Settings (Continued)

Bit(s)	Name	Description
18	FP	Floating-point available 0 = The processor prevents dispatch of floating-point instructions, including floating-point loads, stores and moves. Floating-point enabled program exceptions can still occur and the FPRs can still be accessed. 1 = The processor can execute floating-point instructions, and can take floating-point enabled exception type program exceptions.
19	ME	Machine check enable 0 = Machine check exceptions are disabled. 1 = Machine check exceptions are enabled.
20	FE0	Floating-point exception mode 0 (See **Table 3-11**.)
21	SE	Single-step trace enable 0 = The processor executes instructions normally. 1 = The processor generates a single-step trace exception upon the successful execution of the next instruction. When this bit is set, the processor dispatches instructions in strict program order. Successful execution means the instruction caused no other exception. Single-step tracing may not be present on all implementations.
22	BE	Branch trace enable 0 = No trace exception occurs when a branch instruction is completed 1 = Trace exception occurs when a branch instruction is completed
23	FE1	Floating-point exception mode 1 (See **Table 3-11**.)
24	—	Reserved.
25	IP	Exception prefix. The setting of this bit specifies the location of the exception vector table. 0 = Exception vector table starts at the physical address 0x0000 0000. 1 = Exception vector table starts at the physical address 0xFFF0 0000.
26:29	—	Reserved
30	RI	Recoverable exception (for machine check and non-maskable breakpoint exceptions) 0 = Machine state is not recoverable. 1 = Machine state is recoverable.
31	LE	Little endian mode 0 = Processor operates in big-endian mode during normal processing. 1 = Processor operates in little-endian mode during normal processing.

The floating-point exception mode bits are interpreted as shown in **Table 3-11**.

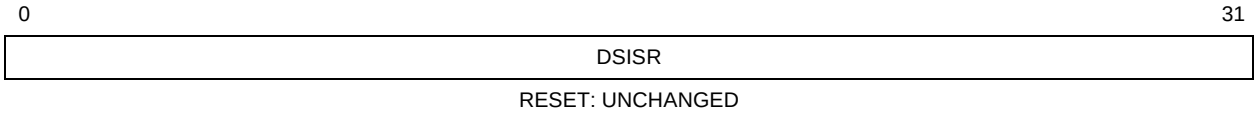
Table 3-11 Floating-Point Exception Mode Bits

FE[0:1]	Mode
00	Ignore exceptions mode — Floating-point exceptions do not cause the floating-point assist error handler to be invoked.
01, 10, 11	Floating-point precise mode — The system floating-point assist error handler is invoked precisely at the instruction that caused the enabled exception.

3.9.2 DAE/Source Instruction Service Register (DSISR)

The 32-bit DSISR identifies the cause of data access and alignment exceptions.

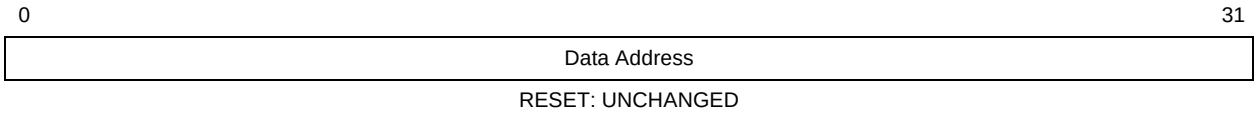
DSISR — DAE/Source Instruction Service Register **SPR 18**



3.9.3 Data Address Register (DAR)

After an alignment exception, the DAR is set to the effective address of a load or store element.

DAR — Data Address Register **SPR 19**



3.9.4 Time Base Facility (TB) — OEA

As described in 3.8 PowerPC VEA Register Set — Time Base, the time base (TB) provides a 64-bit incrementing counter. The VEA defines user-level, read-only access to the TB. Writing to the TB is reserved for supervisor-level applications such as operating systems and bootstrap routines. The OEA defines supervisor-level write access to the TB.

TB — Time Base (Writing) **SPR 284, 285**

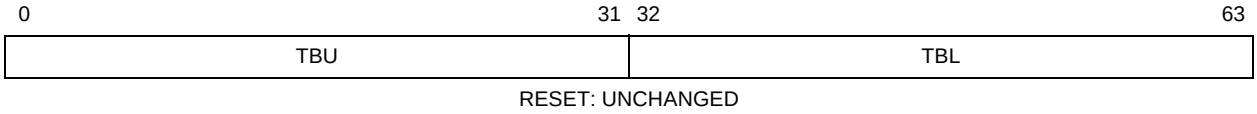


Table 3-12 Time Base Field Definitions

Bits	Name	Description
0:31	TBU	Time Base (Upper) — The high-order 32 bits of the time base
32:63	TBL	Time Base (Lower) — The low-order 32 bits of the time base

The TB can be written at the supervisor privilege level only. The **mttbl** and **mttbu** simplified mnemonics write the lower and upper halves of the TB, respectively. The **mtspr**, **mttbl**, and **mttbu** instructions treat TBL and TBU as separate 32-bit registers; setting one leaves the other unchanged. It is not possible to write the entire 64-bit time base in a single instruction.

For information about reading the time base, refer to 3.8 PowerPC VEA Register Set — Time Base.

3.9.5 Decrementer Register (DEC)

The decrementer (DEC, SPR 22) is a 32-bit decrementing counter defined by the PowerPC architecture to provide a decrementer exception after a programmable delay. The DEC satisfies the following requirements:

- Loading a GPR from the DEC has no effect on the DEC.
- Storing a GPR to the DEC replaces the value in the DEC with the value in the GPR.
- Whenever bit 0 of the DEC changes from zero to one, a decrementer exception request (unless masked) is signaled. Multiple DEC exception requests may be received before the first exception occurs; however, any additional requests are canceled when the exception occurs for the first request.
- If the DEC is altered by software and the content of bit 0 is changed from zero to one, an exception request is signaled.

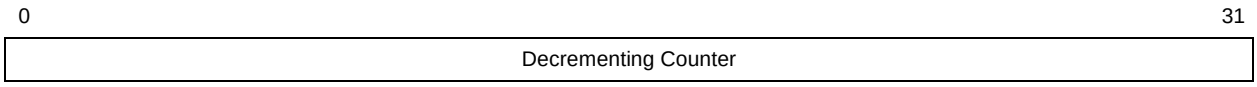
The decrementer frequency is based on a subdivision of the processor clock. In the MPC509, the default frequency is 1 MHz. A bit in the system clock control register (SCCR) in the SIU determines the clock source of both the decrementer and the time base.

With a 1-MHz input frequency, the decrementer period is 4295 seconds (approximately 71.6 minutes):

$$T_{DEC} = 2^{32} / 1\ MHz = 4295\ seconds$$

The state of DEC after standby power is restored is indeterminate. The DEC runs continuously after power-up (unless the clock module is programmed to turn off the clock). System software must perform any initialization. The decrementer is not affected by reset and continues counting while reset is asserted. A decrementer exception may be signaled to software prior to initialization.

DEC — Decrementer Register **SPR 22**

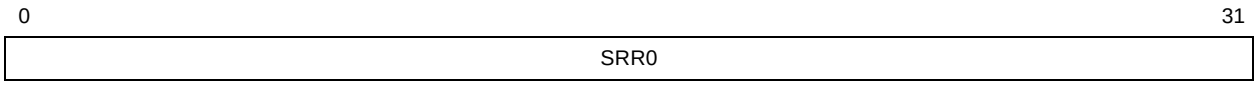


RESET: UNCHANGED

3.9.6 Machine Status Save/Restore Register 0 (SRR0)

The machine status save/restore register 0 (SRR0) is a 32-bit register that identifies where instruction execution should resume when an **rfi** instruction is executed following an exception. It also holds the effective address of the instruction that follows the system call (**sc**) instruction.

SRR0 — Machine Status Save/Restore Register 0 **SPR 26**



RESET: UNDEFINED

When an exception occurs, SRR0 is set to point to an instruction such that all prior instructions have completed execution and no subsequent instruction has begun execution. The instruction addressed by SRR0 may not have completed execution, depending on the exception type. SRR0 addresses either the instruction causing the

exception or the immediately following instruction. The instruction addressed can be determined from the exception type and status bits.

3.9.7 Machine Status Save/Restore Register 1 (SRR1)

SRR1 is a 32-bit register used to save machine status on exceptions and to restore machine status when an **rfi** instruction is executed.

SRR1 — Machine Status Save/Restore Register 1 **SPR 27**

0	31
SRR1	

RESET: UNDEFINED

In general, when an exception occurs, SRR1[0:15] are loaded with exception-specific information, and MSR[16:31] are placed into SRR1[16:31].

3.9.8 General SPRs (SPRG0–SPRG3)

SPRG0–SPRG3 are 32-bit registers provided for general operating system use, such as performing a fast state save and for supporting multiprocessor implementations. SPRG0–SPRG3 are shown below.

SPRG0–SPRG3 — General Special-Purpose Registers 0–3 **SPR 272 – SPR 275**

0	31
SPRG0	
SPRG1	
SPRG2	
SPRG3	

RESET: UNCHANGED

Uses for SPRG0–SPRG3 are shown in **Table 3-13**.

Table 3-13 Uses of SPRG0–SPRG3

Register	Description
SPRG0	Software may load a unique physical address in this register to identify an area of memory reserved for use by the exception handler. This area must be unique for each processor in the system.
SPRG1	This register may be used as a scratch register by the exception handler to save the content of a GPR. That GPR then can be loaded from SPRG0 and used as a base register to save other GPRs to memory.
SPRG2	This register may be used by the operating system as needed.
SPRG3	This register may be used by the operating system as needed.

3.9.9 Processor Version Register (PVR)

The PVR is a 32-bit, read-only register that identifies the version and revision level of the PowerPC processor. The contents of the PVR can be copied to a GPR by the **mfspr** instruction. Read access to the PVR is available in supervisor mode only; write access is not provided.

PVR — Processor Version Register **SPR 287**

0	15	16	31
VERSION		REVISION	

RESET: UNCHANGED

Table 3-14 Processor Version Register Bit Settings

Bit(s)	Name	Description
0:15	VERSION	A 16-bit number that identifies the version of the processor and of the PowerPC architecture
16:31	REVISION	A 16-bit number that distinguishes between various releases of a particular version

3.9.10 Implementation-Specific SPRs

The RCPU includes several implementation-specific SPRs that are not defined by the PowerPC architecture. These registers can be accessed by supervisor-level instructions only.

3.9.10.1 EIE, EID, and NRI Special-Purpose Registers

The RCPU includes three implementation-specific SPRs to facilitate the software manipulation of the MSR[RI] and MSR[EE] bits. Issuing the **mtspr** instruction with one of these registers as an operand causes the RI and EE bits to be set or cleared as shown in **Table 3-15**.

A read (**mfspr**) of any of these locations is treated as an unimplemented instruction, resulting in a software emulation exception.

Table 3-15 Manipulation of MSR[EE] and MSR[RI]

SPR Number (Decimal)	Mnemonic	Effect on MSR Bits	
		MSR[EE]	MSR[RI]
80	EIE	1	1
81	EID	0	1
82	NRI	0	0

3.9.10.2 Instruction-Cache Control Registers

The implementation-specific supervisor-level SPRs shown in **Table 3-16** control the operation of the instruction cache.

Table 3-16 Instruction Cache Control Registers

SPR Number (Decimal)	Mnemonic	Name
560	ICCST	I-cache control and status register
561	ICADR	I-cache address register
562	ICDAT	I-cache data port (read only)

Refer to 4.3 Instruction Cache Programming Model for details on these registers.

3.9.10.3 Development Support Registers

Table 3-17 lists the implementation-specific RCPU registers provided for development support.

Table 3-17 Development Support Registers

SPR Number (Decimal)	Mnemonic	Name
144	CMPA	Comparator A Value Register
145	CMPB	Comparator B Value Register
146	CMPC	Comparator C Value Register
147	CMPD	Comparator D Value Register
148	ECR	Exception Cause Register
149	DER	Debug Enable Register
150	COUNTA	Breakpoint Counter A Value and Control Register
151	COUNTB	Breakpoint Counter B Value and Control Register
152	CMPE	Comparator E Value Register
153	CMPF	Comparator F Value Register
154	CMPG	Comparator G Value Register
155	CMPH	Comparator H Value Register
156	LCTRL1	L-Bus Support Control Register 1
157	LCTRL2	L-Bus Support Control Register 2
158	ICTRL	I-Bus Support Control Register
159	BAR	Breakpoint Address Register
630	DPDR	Development Port Data Register

Refer to the *RCPU Reference Manual* (RCPURM/AD) for detailed descriptions of these registers.

3.9.10.4 Floating-Point Exception Cause Register (FPECR)

The FPECR is a 32-bit supervisor-level internal status and control register used by the floating-point assist software envelope. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information on this register.

3.10 Instruction Set

All PowerPC instructions are encoded as single words (32 bits). Instruction formats are consistent among all instruction types, permitting efficient decoding to occur in parallel with operand accesses. This fixed instruction length and consistent format greatly simplifies instruction pipelining.

The PowerPC instructions are divided into the following categories:

- Integer instructions. These include computational and logical instructions.
  — Integer arithmetic instructions

— Integer compare instructions
— Integer logical instructions
— Integer rotate and shift instructions

- Floating-point instructions. These include floating-point computational instructions, as well as instructions that affect the floating-point status and control register (FPSCR).
  — Floating-point arithmetic instructions
  — Floating-point multiply/add instructions
  — Floating-point rounding and conversion instructions
  — Floating-point compare instructions
  — Floating-point status and control instructions
- Load/store instructions. These include integer and floating-point load and store instructions.
  — Integer load and store instructions
  — Integer load and store multiple instructions
  — Floating-point load and store
  — Primitives used to construct atomic memory operations (**lwarx** and **stwcx.** instructions)
- Flow control instructions. These include branching instructions, condition register logical instructions, trap instructions, and other instructions that affect the instruction flow.
  — Branch and trap instructions
  — Condition register logical instructions
- Processor control instructions. These instructions are used for synchronizing memory accesses and cache management.
  — Move to/from SPR instructions
  — Move to/from MSR
  — Synchronize
  — Instruction synchronize
- Memory control instructions. These instructions provide control of the instruction cache.
  — Supervisor-level cache management instructions
  — User-level cache instructions

Note that this grouping of the instructions does not indicate which execution unit executes a particular instruction or group of instructions.

Integer instructions operate on byte, half-word, and word operands. Floating-point instructions operate on single-precision (one word) and double-precision (one double word) floating-point operands. The PowerPC architecture uses instructions that are four bytes long and word-aligned. It provides for byte, half-word, and word operand loads and stores between memory and a set of 32 GPRs. It also provides for word and double-word operand loads and stores between memory and a set of 32 floating-point registers (FPRs).

Computational instructions do not modify memory. To use a memory operand in a computation and then modify the same or another memory location, the memory contents must be loaded into a register, modified, and then written back to the target location with distinct instructions.

PowerPC processors follow the program flow when they are in the normal execution state. However, the flow of instructions can be interrupted directly by the execution of an instruction or by an asynchronous event. Either kind of exception may cause one of several components of the system software to be invoked.

3.10.1 Instruction Set Summary

Table 3-18 provides a summary of RCPU instructions. Refer to the *RCPU Reference Manual* (RCPURM/AD) for a detailed description of the instruction set.

Table 3-18 Instruction Set Summary

Mnemonic	Operand Syntax	Name
add (add. addo addo.)	**r**D,**r**A,**r**B	Add
addc (addc. addco addco.)	**r**D,**r**A,**r**B	Add Carrying
adde (adde. addeo addeo.)	**r**D,**r**A,**r**B	Add Extended
addi	**r**D,**r**A,SIMM	Add Immediate
addic	**r**D,**r**A,SIMM	Add Immediate Carrying
addic.	**r**D,**r**A,SIMM	Add Immediate Carrying and Record
addis	**r**D,**r**A,SIMM	Add Immediate Shifted
addme (addme. addmeo addmeo.)	**r**D,**r**A	Add to Minus One Extended
addze (addze. addzeo addzeo.)	**r**D,**r**A	Add to Zero Extended
and (and.)	**r**A,**r**S,**r**B	AND
andc (andc.)	**r**A,**r**S,**r**B	AND with Complement
andi.	**r**A,**r**S,UIMM	AND Immediate
andis.	**r**A,**r**S,UIMM	AND Immediate Shifted
b (ba bl bla)	target_addr	Branch
bc (bca bcl bcla)	BO,BI,target_addr	Branch Conditional
bcctr (bcctrl)	BO,BI	Branch Conditional to Count Register
bclr (bclrl)	BO,BI	Branch Conditional to Link Register
cmp	**crf**D,L,**r**A,**r**B	Compare
cmpi	**crf**D,L,**r**A,SIMM	Compare Immediate
cmpl	**crf**D,L,**r**A,**r**B	Compare Logical
cmpli	**crf**D,L,**r**A,UIMM	Compare Logical Immediate
cntlzw (cntlzw.)	**r**A,**r**S	Count Leading Zeros Word
crand	**crb**D,**crb**A,**crb**B	Condition Register AND
crandc	**crb**D,**crb**A,**crb**B	Condition Register AND with Complement
creqv	**crb**D,**crb**A,**crb**B	Condition Register Equivalent
crnand	**crb**D,**crb**A,**crb**B	Condition Register NAND
crnor	**crb**D,**crb**A,**crb**B	Condition Register NOR
cror	**crb**D,**crb**A,**crb**B	Condition Register OR
crorc	**crb**D,**crb**A,**crb**B	Condition Register OR with Complement
crxor	**crb**D,**crb**A,**crb**B	Condition Register XOR
divw (divw. divwo divwo.)	**r**D,**r**A,**r**B	Divide Word
divwu divwu. divwuo divwuo.	**r**D,**r**A,**r**B	Divide Word Unsigned
eieio	—	Enforce In-Order Execution of I/O

Table 3-18 Instruction Set Summary (Continued)

Mnemonic	Operand Syntax	Name
eqv (eqv.)	**r**A,**r**S,**r**B	Equivalent
extsb (extsb.)	**r**A,**r**S	Extend Sign Byte
extsh (extsh.)	**r**A,**r**S	Extend Sign Half Word
fabs (fabs.)	**fr**D,**fr**B	Floating Absolute Value
fadd (fadd.)	**fr**D,**fr**A,**fr**B	Floating Add (Double-Precision)
fadds (fadds.)	**fr**D,**fr**A,**fr**B	Floating Add Single
fcmpo	**crf**D,**fr**A,**fr**B	Floating Compare Ordered
fcmpu	**crf**D,**fr**A,**fr**B	Floating Compare Unordered
fctiw (fctiw.)	**fr**D,**fr**B	Floating Convert to Integer Word
fctiwz (fctiwz.)	**fr**D,**fr**B	Floating Convert to Integer Word with Round toward Zero
fdiv (fdiv.)	**fr**D,**fr**A,**fr**B	Floating Divide (Double-Precision)
fdivs (fdivs.)	**fr**D,**fr**A,**fr**B	Floating Divide Single
fmadd (fmadd.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Multiply-Add (Double-Precision)
fmadds (fmadds.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Multiply-Add Single
fmr (fmr.)	**fr**D,**fr**B	Floating Move Register
fmsub (fmsub.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Multiply-Subtract (Double-Precision)
fmsubs (fmsubs.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Multiply-Subtract Single
fmul (fmul.)	**fr**D,**fr**A,**fr**C	Floating Multiply (Double-Precision)
fmuls (fmuls.)	**fr**D,**fr**A,**fr**C	Floating Multiply Single
fnabs (fnabs.)	**fr**D,**fr**B	Floating Negative Absolute Value
fneg (fneg.)	**fr**D,**fr**B	Floating Negate
fnmadd (fnmadd.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Negative Multiply-Add (Double-Precision)
fnmadds (fnmadds.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Negative Multiply-Add Single
fnmsub (fnmsub.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Negative Multiply-Subtract (Double-Precision)
fnmsubs (fnmsubs.)	**fr**D,**fr**A,**fr**C,**fr**B	Floating Negative Multiply-Subtract Single
frsp (frsp.)	**fr**D,**fr**B	Floating Round to Single
fsub (fsub.)	**fr**D,**fr**A,**fr**B	Floating Subtract (Double-Precision)
fsubs (fsubs.)	**fr**D,**fr**A,**fr**B	Floating Subtract Single
icbi	**r**A,**r**B	Instruction Cache Block Invalidate
isync	—	Instruction Synchronize
lbz	**r**D,d(**r**A)	Load Byte and Zero
lbzu	**r**D,d(**r**A)	Load Byte and Zero with Update
lbzux	**r**D,**r**A,**r**B	Load Byte and Zero with Update Indexed
lbzx	**r**D,**r**A,**r**B	Load Byte and Zero Indexed
lfd	**fr**D,d(**r**A)	Load Floating-Point Double
lfdu	**fr**D,d(**r**A)	Load Floating-Point Double with Update
lfdux	**fr**D,**r**A,**r**B	Load Floating-Point Double with Update Indexed
lfdx	**fr**D,**r**A,**r**B	Load Floating-Point Double Indexed
lfs	**fr**D,d(**r**A)	Load Floating-Point Single

Table 3-18 Instruction Set Summary (Continued)

Mnemonic	Operand Syntax	Name
lfsu	**fr**D,d(**r**A)	Load Floating-Point Single with Update
lfsux	**fr**D,**r**A,**r**B	Load Floating-Point Single with Update Indexed
lfsx	**fr**D,**r**A,**r**B	Load Floating-Point Single Indexed
lha	**r**D,d(**r**A)	Load Half Word Algebraic
lhau	**r**D,d(**r**A)	Load Half Word Algebraic with Update
lhaux	**r**D,**r**A,**r**B	Load Half Word Algebraic with Update Indexed
lhax	**r**D,**r**A,**r**B	Load Half Word Algebraic Indexed
lhbrx	**r**D,**r**A,**r**B	Load Half Word Byte-Reverse Indexed
lhz	**r**D,d(**r**A)	Load Half Word and Zero
lhzu	**r**D,d(**r**A)	Load Half Word and Zero with Update
lhzux	**r**D,**r**A,**r**B	Load Half Word and Zero with Update Indexed
lhzx	**r**D,**r**A,**r**B	Load Half Word and Zero Indexed
lmw	**r**D,d(**r**A)	Load Multiple Word
lswi	**r**D,**r**A,NB	Load String Word Immediate
lswx	**r**D,**r**A,**r**B	Load String Word Indexed
lwarx	**r**D,**r**A,**r**B	Load Word and Reserve Indexed
lwbrx	**r**D,**r**A,**r**B	Load Word Byte-Reverse Indexed
lwz	**r**D,d(**r**A)	Load Word and Zero
lwzu	**r**D,d(**r**A)	Load Word and Zero with Update
lwzux	**r**D,**r**A,**r**B	Load Word and Zero with Update Indexed
lwzx	**r**D,**r**A,**r**B	Load Word and Zero Indexed
mcrf	**crf**D,**crf**S	Move Condition Register Field
mcrfs	**crf**D,**crf**S	Move to Condition Register from FPSCR
mcrxr	**crf**D	Move to Condition Register from XER
mfcr	**r**D	Move from Condition Register
mffs (mffs.)	**fr**D	Move from FPSCR
mfmsr	**r**D	Move from Machine State Register
mfspr	**r**D,SPR	Move from Special Purpose Register
mftb	**r**D,TBR	Move from Time Base
mtcrf	CRM,**r**S	Move to Condition Register Fields
mtfsb0 (mtfsb0.)	**crb**D	Move to FPSCR Bit 0
mtfsb1 (mtfsb1.)	**crb**D	Move to FPSCR Bit 1
mtfsf (mtfsf.)	FM,**fr**B	Move to FPSCR Fields
mtfsfi (mtfsfi.)	**crf**D,IMM	Move to FPSCR Field Immediate
mtmsr	**r**S	Move to Machine State Register
mtspr	SPR,**r**S	Move to Special Purpose Register
mulhw (mulhw.)	**r**D,**r**A,**r**B	Multiply High Word
mulhwu (mulhwu.)	**r**D,**r**A,**r**B	Multiply High Word Unsigned
mulli	**r**D,**r**A,SIMM	Multiply Low Immediate
mullw (mullw. mullwo mullwo.)	**r**D,**r**A,**r**B	Multiply Low
nand (nand.)	**r**A,**r**S,**r**B	NAND
neg (neg. nego nego.)	**r**D,**r**A	Negate

Table 3-18 Instruction Set Summary (Continued)

Mnemonic	Operand Syntax	Name
nor (nor.)	**r**A,**r**S,**r**B	NOR
or (or.)	**r**A,**r**S,**r**B	OR
orc (orc.)	**r**A,**r**S,**r**B	OR with Complement
ori	**r**A,**r**S,UIMM	OR Immediate
oris	**r**A,**r**S,UIMM	OR Immediate Shifted
rfi	—	Return from Interrupt
rlwimi (rlwimi.)	**r**A,**r**S,SH,MB,ME	Rotate Left Word Immediate then Mask Insert
rlwinm (rlwinm.)	**r**A,**r**S,SH,MB,ME	Rotate Left Word Immediate then AND with Mask
rlwnm (rlwnm.)	**r**A,**r**S,**r**B,MB,ME	Rotate Left Word then AND with Mask
sc	—	System Call
slw (slw.)	**r**A,**r**S,**r**B	Shift Left Word
sraw (sraw.)	**r**A,**r**S,**r**B	Shift Right Algebraic Word
srawi (srawi.)	**r**A,**r**S,SH	Shift Right Algebraic Word Immediate
srw (srw.)	**r**A,**r**S,**r**B	Shift Right Word
stb	**r**S,d(**r**A)	Store Byte
stbu	**r**S,d(**r**A)	Store Byte with Update
stbux	**r**S,**r**A,**r**B	Store Byte with Update Indexed
stbx	**r**S,**r**A,**r**B	Store Byte Indexed
stfd	**fr**S,d(**r**A)	Store Floating-Point Double
stfdu	**fr**S,d(**r**A)	Store Floating-Point Double with Update
stfdux	**fr**S,**r**B	Store Floating-Point Double with Update Indexed
stfdx	**fr**S,**r**B	Store Floating-Point Double Indexed
stfiwx	**fr**S,**r**B	Store Floating-Point as Integer Word Indexed
stfs	**fr**S,d(**r**A)	Store Floating-Point Single
stfsu	**fr**S,d(**r**A)	Store Floating-Point Single with Update
stfsux	**fr**S,**r**B	Store Floating-Point Single with Update Indexed
stfsx	**fr**S,**r** B	Store Floating-Point Single Indexed
sth	**r**S,d(**r**A)	Store Half Word
sthbrx	**r**S,**r**A,**r**B	Store Half Word Byte-Reverse Indexed
sthu	**r**S,d(**r**A)	Store Half Word with Update
sthux	**r**S,**r**A,**r**B	Store Half Word with Update Indexed
sthx	**r**S,**r**A,**r**B	Store Half Word Indexed
stmw	**r**S,d(**r**A)	Store Multiple Word
stswi	**r**S,**r**A,NB	Store String Word Immediate
stswx	**r**S,**r**A,**r**B	Store String Word Indexed
stw	**r**S,d(**r**A)	Store Word
stwbrx	**r**S,**r**A,**r**B	Store Word Byte-Reverse Indexed
stwcx.	**r**S,**r**A,**r**B	Store Word Conditional Indexed
stwu	**r**S,d(**r**A)	Store Word with Update
stwux	**r**S,**r**A,**r**B	Store Word with Update Indexed

Table 3-18 Instruction Set Summary (Continued)

Mnemonic	Operand Syntax	Name
stwx	**r**S,**r**A,**r**B	Store Word Indexed
subf (subf. subfo subfo.)	**r**D,**r**A,**r**B	Subtract From
subfc (subfc. subfco subfco.)	**r**D,**r**A,**r**B	Subtract from Carrying
subfe (subfe. subfeo subfeo.)	**r**D,**r**A,**r**B	Subtract from Extended
subfic	**r**D,**r**A,SIMM	Subtract from Immediate Carrying
subfme (subfme. subfmeo subfmeo.)	**r**D,**r**A	Subtract from Minus One Extended
subfze (subfze. subfzeo subfzeo.)	**r**D,**r**A	Subtract from Zero Extended
sync	—	Synchronize
tw	TO,**r**A,**r**B	Trap Word
twi	TO,**r**A,SIMM	Trap Word Immediate
xor (xor.)	**r**A,**r**S,**r**B	XOR
xori	**r**A,**r**S,UIMM	XOR Immediate
xoris	**r**A,**r**S,UIMM	XOR Immediate Shifted

3.10.2 Recommended Simplified Mnemonics

To simplify assembly language coding, a set of alternative mnemonics is provided for some frequently used operations (such as no-op, load immediate, load address, move register, and complement register).

For a complete list of simplified mnemonics, see the *RCPU Reference Manual* (RCPURM/AD). Programs written to be portable across the various assemblers for the PowerPC architecture should not assume the existence of mnemonics not described in that manual.

3.10.3 Calculating Effective Addresses

The effective address (EA) is the 32-bit address computed by the processor when executing a memory access or branch instruction or when fetching the next sequential instruction.

The PowerPC architecture supports two simple memory addressing modes:

- EA = (**r**A|0) + 16-bit offset (including offset = 0) (register indirect with immediate index)
- EA = (**r**A|0) + **r**B (register indirect with index)

These simple addressing modes allow efficient address generation for memory accesses. Calculation of the effective address for aligned transfers occurs in a single clock cycle.

For a memory access instruction, if the sum of the effective address and the operand length exceeds the maximum effective address, the storage operand is considered to wrap around from the maximum effective address to effective address 0.

Effective address computations for both data and instruction accesses use 32-bit unsigned binary arithmetic. A carry from bit 0 is ignored in 32-bit implementations.

3.11 Exception Model

The PowerPC exception mechanism allows the processor to change to supervisor state as a result of external signals, errors, or unusual conditions arising in the execution of instructions. When exceptions occur, information about the state of the processor is saved to certain registers, and the processor begins execution at an address (exception vector) predetermined for each exception. Processing of exceptions occurs in supervisor mode.

Although multiple exception conditions can map to a single exception vector, a more specific condition may be determined by examining a register associated with the exception — for example, the DAE/source instruction service register (DSISR) and the floating-point status and control register (FPSCR). Additionally, some exception conditions can be explicitly enabled or disabled by software.

3.11.1 Exception Classes

The MPC509 exception classes are shown in **Table 3-19**.

Table 3-19 MPC509 Exception Classes

Class	Exception Type
Asynchronous, unordered	Machine check System reset
Asynchronous, ordered	External interrupt Decrementer
Synchronous (ordered, precise)	Instruction-caused exceptions

3.11.2 Ordered Exceptions

In the MPC509, all exceptions except for reset, debug port non-maskable interrupts, and machine check exceptions are ordered. Ordered exceptions satisfy the following criteria:

- Only one exception is reported at a time. If, for example, a single instruction encounters multiple exception conditions, those conditions are encountered sequentially. After the exception handler handles an exception, instruction execution continues until the next exception condition is encountered.
- When the exception is taken, no program state is lost.

3.11.3 Unordered Exceptions

Unordered exceptions may be reported at any time and are not guaranteed to preserve program state information. The processor can never recover from a reset exception. It can recover from other unordered exceptions in most cases. However, if a debug port non-maskable interrupt or machine check exception occurs during the servicing of a previous exception, the machine state information in SRR0 and SRR1 (and, in some cases, the DAR and DSISR) may not be recoverable; the processor may be in the process of saving or restoring these registers.

To determine whether the machine state is recoverable, the user can read the RI (recoverable exception) bit in SRR1. During exception processing, the RI bit in the

MSR is copied to SRR1 and then cleared. The operating system should set the RI bit in the MSR at the end of each exception handler's prologue (after saving the program state) and clear the bit at the start of each exception handler's epilogue (before restoring the program state). Then, if an unordered exception occurs during the servicing of an exception handler, the RI bit in SRR1 will contain the correct value.

3.11.4 Precise Exceptions

In the MPC509, all synchronous (instruction-caused) exceptions are precise. When a precise exception occurs, the processor backs the machine up to the instruction causing the exception. This ensures that the machine is in its correct architecturally-defined state. The following conditions exist at the point a precise exception occurs:

1. Architecturally, no instruction following the faulting instruction in the code stream has begun execution.
2. All instructions preceding the faulting instruction appear to have completed with respect to the executing processor.
3. SRR0 addresses either the instruction causing the exception or the immediately following instruction. Which instruction is addressed can be determined from the exception type and the status bits.
4. Depending on the type of exception, the instruction causing the exception may not have begun execution, may have partially completed, or may have completed execution.

3.11.5 Exception Vector Table

The setting of the exception prefix (IP) bit in the MSR determines how exceptions are vectored. If the bit is cleared, the exception vector table begins at the physical address 0x0000 0000; if IP is set, the exception vector table begins at the physical address 0xFFF0 0000. **Table 3-20** shows the exception vector offset of the first instruction of the exception handler routine for each exception type.

Table 3-20 Exception Vector Offset Table

Vector Offset (Hexadecimal)	Exception Type
00000	Reserved
00100	System reset
00200	Machine check
00300	Data access
00400	Instruction access
00500	External interrupt
00600	Alignment
00700	Program
00800	Floating-point unavailable
00900	Decrementer
00A00	Reserved
00B00	Reserved
00C00	System call
00D00	Trace
00E00	Floating-point assist
01000	Software emulation
01C00	Data breakpoint
01D00	Instruction breakpoint
01E00	Maskable external breakpoint
01F00	Non-maskable external breakpoint

3.12 Instruction Timing

The MPC509 processor is pipelined. Because the processing of an instruction is broken into a series of stages, an instruction does not require the entire resources of the processor.

The instruction pipeline in the MPC509 has four stages:

1. The dispatch stage is implemented using a distributed mechanism. The central dispatch unit broadcasts the instruction to all units. In addition, scoreboard information (regarding data dependencies) is broadcast to each execution unit. Each execution unit decodes the instruction. If the instruction is not implemented, a program exception is taken. If the instruction is legal and no data dependency is found, the instruction is accepted by the appropriate execution unit, and the data found in the destination register is copied to the history buffer. If a data dependency exists, the machine is stalled until the dependency is resolved.
2. In the execute stage, each execution unit that has an executable instruction executes the instruction. (For some instructions, this occurs over multiple cycles).
3. In the writeback stage, the execution unit writes the result to the destination register and reports to the history buffer that the instruction is completed.
4. In the retirement stage, the history buffer retires instructions in architectural or-

der. An instruction retires from the machine if it completes execution with no exceptions and if all instructions preceding it in the instruction stream have finished execution with no exceptions. As many as six instructions can be retired in one clock.

The history buffer maintains the correct architectural machine state. An exception is taken only when the instruction is ready to be retired from the machine (i.e., after all previously-issued instructions have already been retired from the machine). When an exception is taken, all instructions following the excepting instruction are canceled, i.e., the values of the affected destination registers are restored using the values saved in the history buffer during the dispatch stage.

Figure 3-4 shows basic instruction pipeline timing.

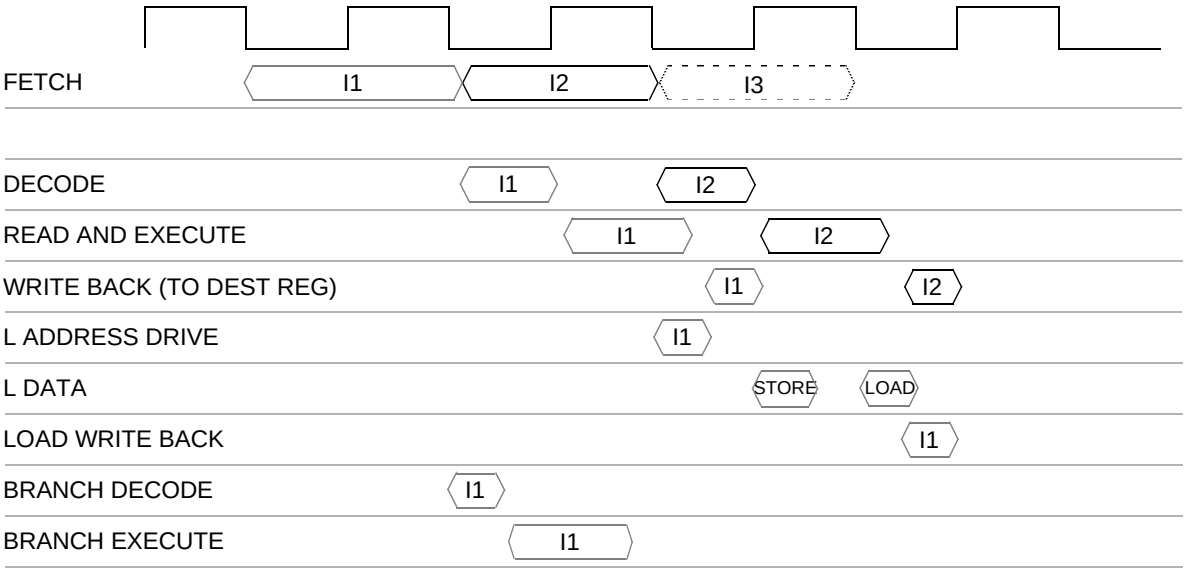


Figure 3-4 Basic Instruction Pipeline

Table 3-21 indicates the latency and blockage for each type of instruction. Latency refers to the interval from the time an instruction begins execution until it produces a result that is available for use by a subsequent instruction. Blockage refers to the interval from the time an instruction begins execution until its execution unit is available for a subsequent instruction. Note that when the blockage equals the latency, it is not possible to issue another instruction to the same unit in the same cycle in which the first instruction is being written back.

Table 3-21 Instruction Latency and Blockage

Instruction Type	Precision	Latency	Blockage
Floating-point multiply-add	Double Single	7 6	7 6
Floating-point add or subtract	Double Single	4 4	4 4
Floating-point multiply	Double Single	5 4	5 4
Floating-point divide	Double Single	17 10	17 10
Integer multiply	—	2	1 or 2[1]
Integer divide	—	2 to 11[1]	2 to 11[1]
Integer load/store	—	See note[1]	See note[1]

NOTES:

1. Refer to Section 7, “Instruction Timing,” in the *RCPU Reference Manual* (RCPURM/AD) for details.

SECTION 4
INSTRUCTION CACHE

The MPC509 instruction cache (I-cache) is a 4-Kbyte, two-way set associative cache. The cache is organized into 128 sets, with two lines per set and four words per line. Cache lines are aligned on four-word boundaries in memory.

A cache access cycle begins with an instruction request from the CPU instruction unit. In case of a cache hit, the instruction is delivered to the instruction unit. In case of a cache miss, the cache initiates a burst read cycle (four beats per burst, one word per beat) on the instruction bus (I-bus) with the address of the requested instruction. The first word received from the bus is the requested instruction. The cache forwards this instruction to the instruction unit as soon as it is received from the I-bus. A cache line is then selected to receive the data which will be coming from the bus. An LRU (least recently used) replacement algorithm is used to select a line when no empty lines are available.

Each cache line can be used as an SRAM, allowing the application to lock critical code segments that need fast and deterministic execution time.

Cache coherency in a multi-processor environment is maintained by software and supported by a fast hardware invalidation capability.

4.1 Instruction Cache Features

- Four Kbytes, two-way set associative, four words in a line
- LRU replacement policy
- Lockable SRAM (cache line granularity)
- Critical word first burst access
- Stream hit (allows fetch from the burst buffer and of the word currently on the I-bus)
- Efficiently utilizes the pipeline of the I-bus by initiating a new burst cycle (if miss is detected) while delivering the tail of the previous missed line to the instruction unit
- Cache control:
  — Supports PowerPC invalidate instruction
  — Supports load and lock (cache line granularity)
- Supports cache inhibit:
  — As a cache mode of operation (cache disable)
  — On memory regions (supported by the chip select logic)
- Miss latency is reduced by
  — Sending address to the cache and to the I-bus simultaneously; and
  — Aborting on cache hit before cycle is mapped externally
- Minimum operational power consumption
- Supports reads of tags (including all attributes) and data arrays (for debugging

purposes)

4.2 Instruction Cache Organization

Figure 4-1 illustrates the I-cache organization.

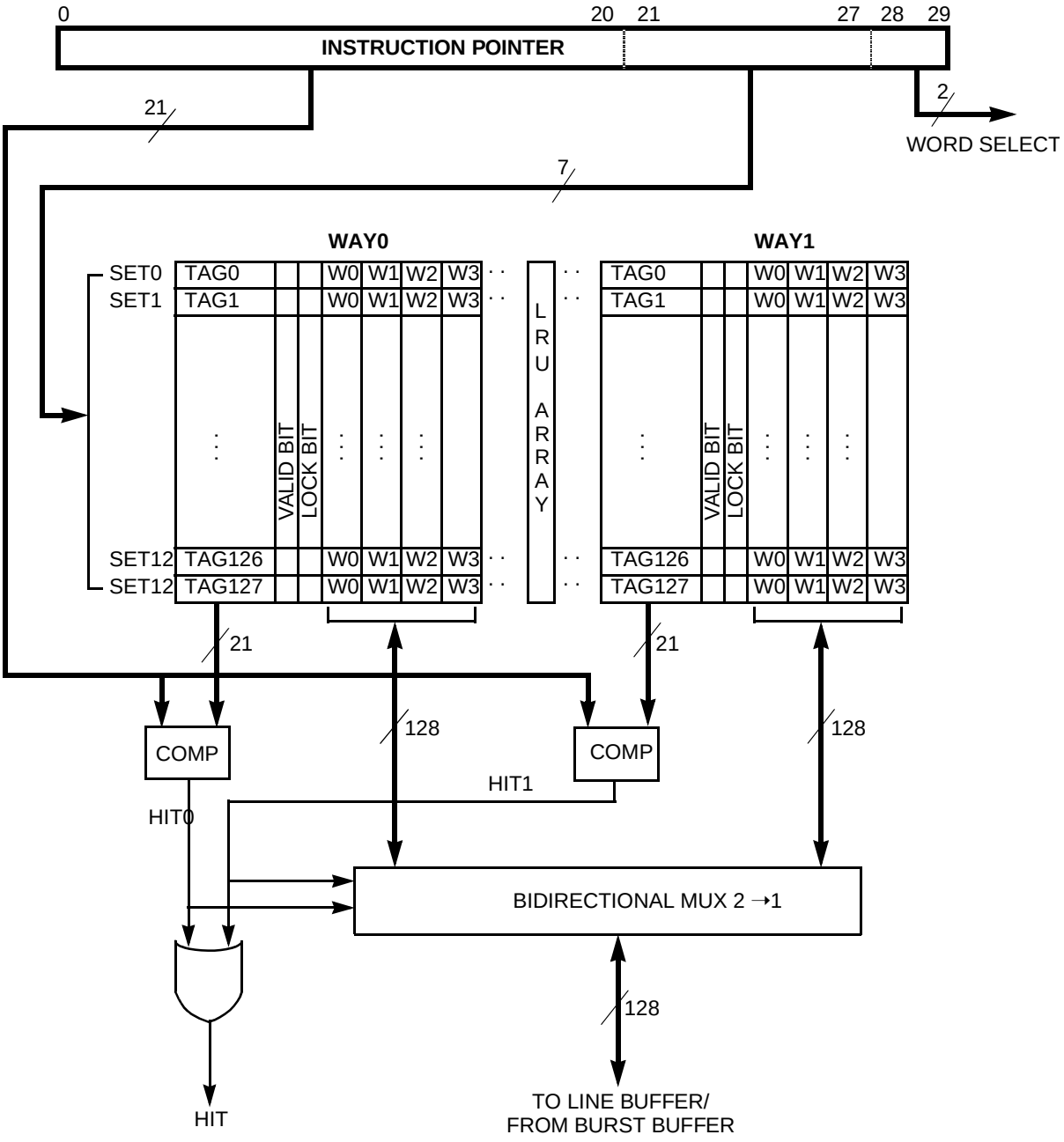


Figure 4-1 Instruction Cache Organization

Figure 4-2 illustrates the data path of the I-cache.

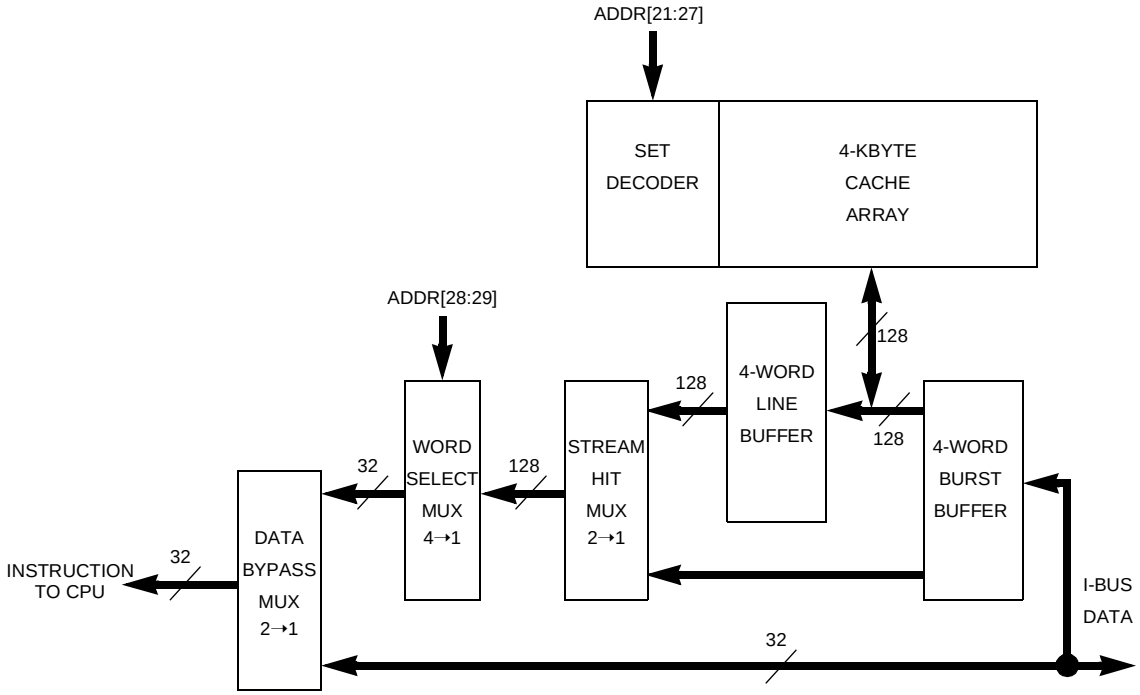


Figure 4-2 Instruction Cache Data Path

4.3 Instruction Cache Programming Model

Three special purpose registers (SPRs) control the I-cache:

Table 4-1 Instruction Cache Programming Model

Name	SPR Number (Decimal)	Description
ICCST	560	I-cache control and status register
ICADR	561	I-cache address register
ICDAT	562	I-cache data port (read only)

These registers are privileged; attempting to access them when the CPU is operating at the user privilege level results in a program exception.

ICCST — I-Cache Control and Status Register **SPR560**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
IEN	RESERVED			CMD			RESERVED			CCER 1	CCER 2	CCER 3	RESERVED		
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-2 ICCST Bit Settings

Bits	Mnemonic	Description
0	IEN	I-cache enable status bit. This bit is a read-only bit. Any attempt to write it is ignored. 0 = I-cache is disabled 1 = I-cache is enabled
1:3	—	Reserved
4:6	CMD	I-Cache Command 000 = No command 001 = **Cache enable** 010 = **Cache disable** 011 = **Load & lock** 100 = **Unlock line** 101 = **Unlock all** 110 = **Invalidate all** 111 = Reserved
7:9	—	Reserved
10	CCER1	I-Cache Error Type 1 (sticky bit) 0 = No error 1 = Error
11	CCER2	I-Cache Error Type 2 (sticky bit) 0 = No error 1 = Error
12	CCER3	I-Cache Error Type 3 (sticky bit) 0 = No error 1 = Error
13:31	—	Reserved

ICADR — I-Cache Address Register **SPR561**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
ADR																															
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-3 I-Cache Address Register (ICADR)

Bits	Mnemonic	Description
0:31	ADR	The address to be used in the command programmed in the control and status register

ICSDAT — I-Cache Data Register **SPR 562**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DAT																															
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-4 I-Cache Data Register (ICDAT)

Bits	Mnemonic	Description
0:31	DAT	The data received when reading information from the I-cache

4.4 Cache Operation

On an instruction fetch, bits 21:27 of the instruction's address are used as an index into the cache to retrieve the tags and data of one set. The tags from both accessed lines are then compared to bits 0:20 of the instruction's address. If a match is found and the matched entry is valid, then the access is a cache hit.

If neither tag matches or if the matched tag is not valid, the access is a cache miss.

The I-cache includes one burst buffer that holds the last line received from the bus, and one line buffer that holds the last line received from the cache array. If the requested data is found in one of these buffers, the access is considered a cache hit.

To minimize power consumption, the I-cache attempts to make use of data stored in one of its internal buffers. Using a special indication from the CPU, it is also possible, in some cases, to detect that the requested data is in one of the buffers early enough so the cache array is not activated at all.

4.4.1 Cache Hit

On a cache hit, bits 28:29 of the instruction's address are used to select one word from the cache line whose tag matched. In the same clock cycle, the instruction is transferred to the instruction unit of the processor.

4.4.2 Cache Miss

On a cache miss, the address of the missed instruction is driven on the I-bus with a four-word burst transfer read request. A cache line is then selected to receive the data that will be coming from the bus. The selection algorithm gives first priority to invalid lines. If neither of the two candidate lines in the selected set are invalid, then the least recently used line is selected for replacement. Locked lines are never replaced.

The transfer begins with the word requested by the instruction unit (critical word first), followed by any remaining words of the line, then by any remaining words at the beginning of the line (wrap around). As the missed instruction is received from the bus, it is immediately delivered to the instruction unit and also written to the burst buffer.

As subsequent instructions are received from the bus they are also written into the burst buffer and, if needed, delivered to the instruction unit (stream hit) either directly from the bus or from the burst buffer. When the entire line resides in the burst buffer, it is written to the cache array if the cache array is not busy with an instruction unit request.

If a bus error is encountered on the access to the requested instruction, a machine check interrupt is taken. If a bus error occurs on any access to other words in the line, the burst buffer is marked invalid and the line is not written to the array. If no bus error is encountered, the burst buffer is marked valid and eventually is written to the array.

Together with the missed word, an indication may arrive from the I-bus that the memory device is non-cacheable. If such an indication is received, the line is not written to the cache, so that subsequent references to the same line will cause the line to be refetched.

4.5 Cache Commands

The MPC509 instruction cache supports the PowerPC invalidate instruction together with some additional commands that help control the cache and debug the information stored in it. The additional commands are implemented using the three special purpose control registers ICCST, ICADR, and ICDAT.

Most of the commands are executed immediately after the control register is written and cannot generate any errors. When these commands are executed, there is no need to check the error status in the ICCST.

Some commands may take longer and may generate errors. In the MPC509, only **load & lock** is such a command. When executing this command, the user needs to insert an **isync** instruction immediately after the I-cache command and check the error status in the ICCST after the **isync**. The error type bits in the ICCST are sticky, allowing the user to perform a series of I-cache commands before checking the termination status. These bits are set by hardware and cleared by software.

All cache commands except the **icbi** CPU instruction require setting the appropriate bits in the ICCST. Since the ICCST is a supervisor-level register, only the **icbi** instruction can be performed at the user privilege level.

4.5.1 Instruction Cache Block Invalidate

The MPC509 implements the PowerPC instruction cache block invalidate (**icbi**) as if it pertains only to the MPC509 instruction cache. This instruction does not broadcast on the external bus and the CPU does not snoop this instruction if broadcast by other masters.

This command is not privileged and has no error cases that the user needs to check.

4.5.2 Invalidate All

To invalidate the whole cache, set the **invalidate all** command in the ICCST. This command has no error cases that the user needs to check.

The command makes all valid lines in the cache invalid, except lines that are locked. After this command is executed, the LRU pointer of each set points to an unlocked way. If both lines in the set are unlocked, the LRU pointer points to way zero. This last feature is useful in order to initialize the I-cache out of reset.

4.5.3 Load and Lock

The **load & lock** operation is used to lock critical code segments in the cache. The **load & lock** operation is performed on a single cache line. After a line is locked it operates as a regular instruction SRAM; it will not be replaced during future misses and will not be affected by invalidate commands.

After the **load & lock** command is written to the ICCST, the cache checks if the line containing the byte addressed by the ICADR is in the cache. If it is, the line is locked and the command terminates with no exception. If the line is not in the cache a regular miss sequence is initiated. After the whole line is placed in the cache the line is locked.

The user needs to check the error type bits in the ICCST to determine if the operation completed properly or not. The **load & lock** command can generate two errors:

- Type 1 — bus error in one of the cycles that fetches the line.
- Type 2 — no place to lock. It is the responsibility of the user to make sure that there is at least one unlocked way in the appropriate set.

4.5.4 Unlock Line

The **unlock line** operation is used to unlock locked cache lines. The **unlock line** operation is performed on a single cache line. If the line is found in the cache (cache hit), it is unlocked and starts to operate as a regular valid cache line. If the line is not found in the cache (cache miss), no operation is performed, and the command terminates with no exception.

This command has no error cases that the user needs to check.

4.5.5 Unlock All

The **unlock all** operation is used to unlock the whole cache. This operation is performed on all cache lines. If a line is locked, it is unlocked and starts to operate as a regular valid cache line. If a line is not locked or if it is invalid, no operation is performed.

This command has no error cases that the user needs to check.

4.5.6 Cache Enable

To enable the cache, set the **cache enable** command in the ICCST. This operation can be performed only at the supervisor privilege level. The **cache enable** command has no error cases that the user needs to check.

Following reset, the **invalidate all** and **unlock all** commands must be performed before the **cache enable** command.

4.5.7 Cache Disable

To disable the cache, set the **cache disable** command in the ICCST. This operation can be performed only at the supervisor privilege level. The cache disable command has no error cases that the user needs to check.

4.5.8 Cache Inhibit

A memory region can be programmed in the chip select logic to be cache inhibit. Any reference to a cache inhibited memory region always results in cache miss.

4.5.9 Cache Read

The user can read all data stored in the instruction cache, including the data stored in the tags array.

To read the data that is stored in the I-cache, follow these steps:

1. Write to the ICADR the address of the data to be read. Note that it is also possible to read this register for debugging purposes.
2. Read the ICDAT.

So that all parts of the I-cache can be accessed, the ICADR is divided into several fields, shown in **Table 4-5**.

Table 4-5 ICADR Bits Function for the Cache Read Command

0:17	18	19	20	21:27	28:29	30:31
Reserved	0 = tag 1 = data	0 = way 0 1 = way 1	Reserved	Set select	Word select (used only for data array)	Reserved

When the data array is read from, the 32 bits of the word selected by the ICADR are placed in the target general-purpose register.

When the tag array is read, the 21 bits of the tag selected by the ICADR, along with additional information, are placed in the target general-purpose register. **Table 4-6** illustrates the bits layout of the I-cache data register when a tag is read.

Table 4-6 ICDAT Layout During a Tag Read

0:20	21	22	23	24	25:31
Tag value	Reserved	0 = not valid 1 = valid	0 = not locked 1 = locked	LRU bit	Reserved

SECTION 5
SYSTEM INTERFACE UNIT

The system interface unit (SIU) consists of modules that control the buses of the chip, provide the clocks, and provide miscellaneous functions for the system, such as chip selects, test control, reset control, and I/O ports.

The MPC509 has an internal Harvard architecture and a single external bus. The internal buses are the instruction bus (I-bus) and the load/store bus (L-bus). The external bus interface (EBI) connects each of these internal buses with the external bus (E-bus). The chip select block provides user-programmable chip selects to select external memory or peripherals. The clock block controls the generation of the system clocks and such features as programmability of the clocks and low-power modes. The reset control function interfaces to the reset pins and provides a reset status register. The general-purpose I/O ports provide untimed I/O functions on pins that are not used for their primary function.

5.1 SIU Block Diagram

A block diagram of the SIU is shown in **Figure 5-1**.

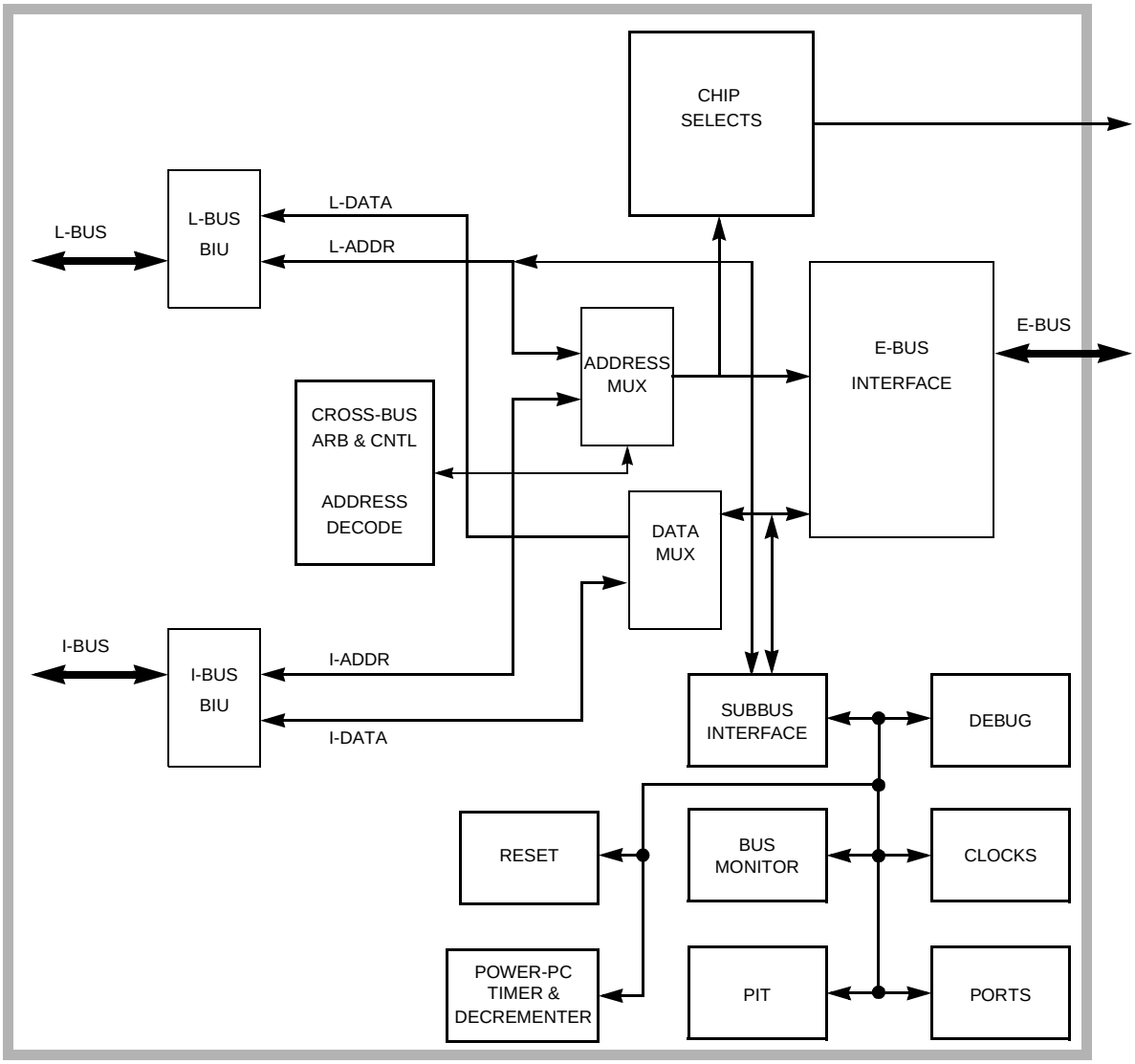


Figure 5-1 SIU Block Diagram

5.2 SIU Address Map

Table 5-1 is an address map of the SIU registers. An entry of “S” in the Access column indicates that the register is accessible in supervisor mode only. “S/U” indicates that the register can be programmed to the desired privilege level. “Test” indicates that the register is accessible in test mode only.

Table 5-1 SIU Address Map

Access	Address	Register
S	0x8007 FC00	SIU Module Configuration Register (SIUMCR)
Test	0x8007 FC04	SIU Test Register 1 (SIUTEST1)
—	0x8007 FC08 – 0x8007 FC1C	Reserved
S	0x8007 FC20	Memory Mapping (MEMMAP)
S	0x8007 FC24	Speculative Address Register (SPECADDR)
S	0x8007 FC28	Speculative Mask Register (SPECMASK)
Test	0x8007 FC2C	Termination Status Register (TERMSTAT)
—	0x8007 FC30 – 0x8007 FC3C	Reserved
S/U	0x8007 FC40	Periodic Interrupt Control and Status Register (PICSR)
S/U	0x8007 FC44	Periodic Interrupt Timer Register (PIT)
S	0x8007 FC48	Bus Monitor Control Register (BMCR)
S	0x8007 FC4C	Reset Status Register (RSR)
S	0x8007 FC50	System Clock Control Register (SCCR)
S	0x8007 FC54	System Clock Lock and Status Register (SCLSR)
—	0x8007 FC58 – 0x8007 FC5C	Reserved
S	0x8007FC60	Port M Data Direction (DDRM)
S	0x8007FC64	Port M Pin Assignment (PMPAR)
S/U	0x8007FC68	Port M Data (PORTM)
—	0x8007FC6C – 0x8007FC80	Reserved
S	0x8007FC84	Port A, B Pin Assignment (PAPAR, PBPAR)
S/U	0x8007FC88	Port A, B Data (PORTA, PORTB)
—	0x8007FC8C – 0x8007FC94	Reserved
S	0x8007FC98	Port I, J, K, L Data Direction (DDRI, DDRJ, DDRK, DDRL)
S	0x8007FC9C	Port I, J, K, L Pin Assignment (PIPAR, PJPAR, PKPAR, PLPAR)
S/U	0x8007FCA0	Port I, J, K, L Data (PORTI, PORTJ, PORTK, PORTL)
—	0x8007 FCA4 – 0x8007 FD94	Reserved
S	0x8007 FD94	$\overline{\text{CS11}}$ Option Register (CSOR11)
S	0x8007 FD98	Reserved
S	0x8007 FD9C	$\overline{\text{CS10}}$ Option Register (CSOR10)
S	0x8007 FDA0	Reserved
S	0x8007 FDA4	$\overline{\text{CS9}}$ Option Register (CSOR9)
S	0x8007 FDA8	Reserved
S	0x8007 FDAC	$\overline{\text{CS8}}$ Option Register (CSOR8)
S	0x8007 FDB0	Reserved
S	0x8007 FDB4	$\overline{\text{CS7}}$ Option Register (CSOR7)
S	0x8007 FDB8	Reserved
S	0x8007 FDBC	$\overline{\text{CS6}}$ Option Register (CSOR6)

Table 5-1 SIU Address Map (Continued)

Access	Address	Register
S	0x8007 FDC0	$\overline{CS5}$ Base Address Register (CSBAR5)
S	0x8007 FDC4	$\overline{CS5}$ Option Register (CSOR5)
S	0x8007 FDC8	$\overline{CS4}$ Base Address Register (CSBAR4)
S	0x8007 FDCC	$\overline{CS4}$ Option Register (CSOR4)
S	0x8007 FDD0	$\overline{CS3}$ Base Address Register (CSBAR3)
S	0x8007 FDD4	$\overline{CS3}$ Option Register (CSOR3)
S	0x8007 FDD8	$\overline{CS2}$ Base Address Register (CSBAR2)
S	0x8007 FDDC	$\overline{CS2}$ Option Register (CSOR2)
S	0x8007 FDE0	$\overline{CS1}$ Base Address Register (CSBAR1)
S	0x8007 FDE4	$\overline{CS1}$ Option Register (CSOR1)
S	0x8007 FDE8	Reserved
S	0x8007 FDEC	$\overline{CS0}$ Option Register (CSOR0)
S	0x8007 FDF0	$\overline{CSBOOT}$ Sub-Block Base Address Register (CSBTSBBAR)
S	0x8007 FDF4	$\overline{CSBOOT}$ Sub-Block Option Register (CSBTSBOR)
S	0x8007 FDF8	$\overline{CSBOOT}$ Base Address Register (CSBTBAR)
S	0x8007 FDFC	$\overline{CSBOOT}$ Option Register (CSBTOR)

5.3 SIU Module Configuration

The SIU module configuration register (SIUMCR) configures various aspects of SIU operation. The internal memory mapping register (MEMMAP) enables and sets the base address of the L-bus and I-bus internal memory blocks. These registers are accessible in supervisor mode only.

5.3.1 SIU Module Configuration Register

The SIU module configuration register (SIUMCR) configures various aspects of SIU operation. This register is accessible in supervisor mode only.

SIUMCR — SIU Module Configuration Register **0x8007 FC00**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SIU-FRZ	RESERVED		CSR	LST	0	SUP		DLK	LOK	RESERVED				LSHOW	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
PARTNUM								MASKNUM							
RESET:															
Read-Only Fixed Value								Read-Only Fixed Value							

Table 5-2 SIUMCR Bit Settings

Bit(s)	Name	Description
0	SIUFRZ	SIU freeze 0 = Decrementer and time base registers and the periodic interrupt timer continue to run while internal freeze signal is asserted (reset value). 1 = Decrementer and time base registers and the periodic interrupt timer stop while the internal freeze signal is asserted. Refer to **5.3.3 Internal Module Select Logic** and **SECTION 8 DEVELOPMENT SUPPORT** for information on the freeze signal.
1:2	—	Reserved
3	CSR	Checkstop reset enable 0 = No action taken when SIU receives the checkstop signal from the CPU and debug mode not enabled (reset value). 1 = SIU causes a reset upon receiving checkstop signal from CPU and debug mode not enabled. If debug mode is enabled, the MCU enters debug mode when the checkstop signal is received, regardless of CSR value. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information on checkstop resets.
4	LST	Burst style: $\overline{\text{BDIP}}$ or $\overline{\text{LAST}}$ 0 = $\overline{\text{BDIP}}$ pin uses $\overline{\text{BDIP}}$ timing (reset value): assert $\overline{\text{BDIP}}$ during burst, negate $\overline{\text{BDIP}}$ during last beat of burst 1 = $\overline{\text{BDIP}}$ pin uses $\overline{\text{LAST}}$ timing: assert $\overline{\text{LAST}}$ during last beat of burst Refer to **5.5.16.6 Synchronous Burst Interface** for more information.
5	—	Reserved
6:7	SUP	Supervisor/unrestricted space. These bits control access to certain SIU registers. (Other registers are always supervisor access only.) The access restrictions for each register are shown in **Table 5-1**. 00 = Unrestricted access (reset value) 01 = Supervisor mode access only 10 = Supervisor mode write access only, unrestricted read access 11 = Supervisor mode access only
8	DLK	Debug register lock. This bit can be written only when internal freeze signal is asserted. DLK allows development software to configure show cycles and prevent normal software from subsequently changing this configuration. This bit overrides the LOK in controlling the LSHOW field. 0 = LSHOW field in SIUMCR can be written to (reset value). 1 = Writes to LSHOW field are not allowed.
9	LOK	Register lock. Once this bit is set, writes to the SIUMCR and chip-select registers have no effect and cause a data error to be generated in the internal bus. In normal operation, this is a set-only bit; once set, it cannot be cleared by software. When the internal freeze signal is asserted, the bit can be set or cleared by software. 0 = Normal operation (reset value) 1 = All bits in the SIUMCR and all of the chip-select registers are locked
10:13	—	Reserved
14:15	LSHOW	L-bus show cycles 00 = Disable show cycles for all internal L-bus cycles (reset value) 01 = Show address and data of all internal L-bus write cycles 10 = Reserved 11 = Show address and data of all internal L-bus cycles Refer to **5.4.13 Show Cycles** for more information.
16:23	PARTNUM	Part number. This read-only field is mask programmed with a code corresponding to the number of the MCU.
24:31	MASKNUM	Mask number. This read-only field is mask programmed with a code corresponding to the mask number of the MCU.

5.3.2 Memory Mapping Register

The internal memory mapping register (MEMMAP) enables and sets the base address of the L-bus (SRAM) internal memory block. This register is accessible in supervisor mode only.

MEMMAP — Memory Mapping Register **0x8007 FC20**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LEN	RESERVED							LMEMBASE		RESERVED					
RESET:															
*	0	0	0	0	0	0	0	*	*	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
IEN	LIX	RESERVED						IMEMBASE		RESERVED					
RESET:															
*	1	0	0	0	0	0	0	*	*	0	0	0	0	0	0

* Reset value depends on the value of the data bus configuration word during reset.

Table 5-3 MEMMAP Bit Settings

Bit(s)	Name	Description
0	LEN	L-bus memory enable 0 = L-bus memory disabled 1 = L-bus memory enabled Reset state depends on the value of the data bus configuration word.
1:7	—	Reserved
8:9	LMEMBASE	Base address of the L-bus memory block 00 = Starting address is 0x0000 0000 01 = Ending address is 0x000F EFFF 10 = Starting address is 0xFFF0 0000 11 = Ending address is 0xFFFF EFFF Reset value depends on the data bus configuration word.
10:15	—	Reserved
16	IEN	I-bus memory enable. This bit has no effect on the MPC509, which has no I-bus memory. 0 = I-bus memory disabled 1 = I-bus memory enabled
17	LIX	L-bus to I-bus cross-bus access enable 0 = Disable data accesses to I-bus memory 1 = Enable data accesses to I-bus memory (reset value)
18:23	—	Reserved
24:25	IMEMBASE	Base address of the I-bus memory block 00 = Starting address is 0x0000 0000 01 = Ending address is 0x000F FFFC 10 = Starting address is 0xFFF0 0000 11 = Ending address is 0xFFFF FFFC Reset state depends on the data bus configuration word.
26:31	—	Reserved

5.3.3 Internal Module Select Logic

The SIU has a unified memory map for the L-bus and the I-bus. The I-bus has two masters, the RCPU and the SIU. The SIU is designed so that one or more memory modules, such as flash EEPROM or instruction RAM, may be located on the I-bus. On the MPC509, however, no memory modules are located on the I-bus.

The L-bus has at least two masters, the RCPU and the SIU. One or more slave modules may reside on the L-bus. These may include memory modules (RAM, flash EEPROM) and on-chip (IMB2) peripherals, which are connected via the L-bus IMB2 interface (LIMB). On the MPC509, the SRAM module is located on the L-bus.

Each module on either bus has one or more internal control registers which control the configuration and operation of the module. On a memory module (i.e., the SRAM on the MPC509), these registers are not mapped with the memory array, but stay at a fixed address in the memory map.

Capability is provided to allow masters on one bus to access slaves on the opposite bus. L-bus masters must be able to access peripherals on the I-bus to program their control registers or to program flash memory arrays. This is because the CPU instruction fetch unit can only run read cycles. Similarly, I-bus masters are able to execute diagnostic programs out of the RAM on the L-bus. These capabilities require that the addresses of the memory modules on the I-bus be known to the L-bus address decode logic and vice versa. Refer to 5.3.4 Internal Cross-Bus Accesses for details.

A block diagram of the internal module select scheme is shown in **Figure 5-2**.

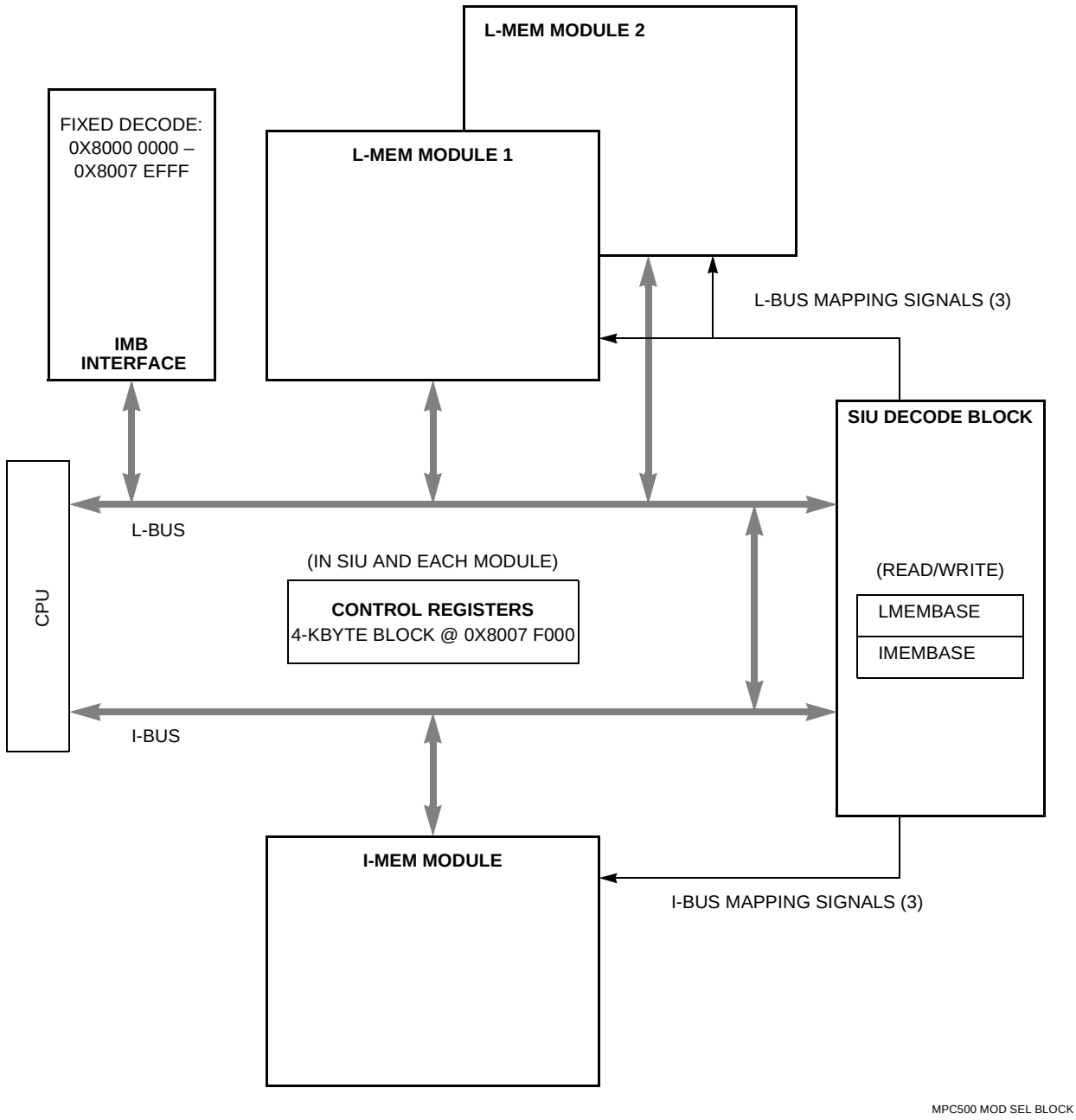


Figure 5-2 Internal Module Select Scheme

5.3.3.1 Memory Block Mapping

The SRAM array can be mapped to one of four locations. These locations are at the top and bottom of the 4-Gbyte address range. They include the two alternatives for the PowerPC vector map (0x0000 0100 and 0xFFFF 0100). The LMEMBASE field in the memory mapping register (MEMMAP) determine the locations of the SRAM array.

Figure 5-3 shows the mapping of the memory blocks within the memory map.

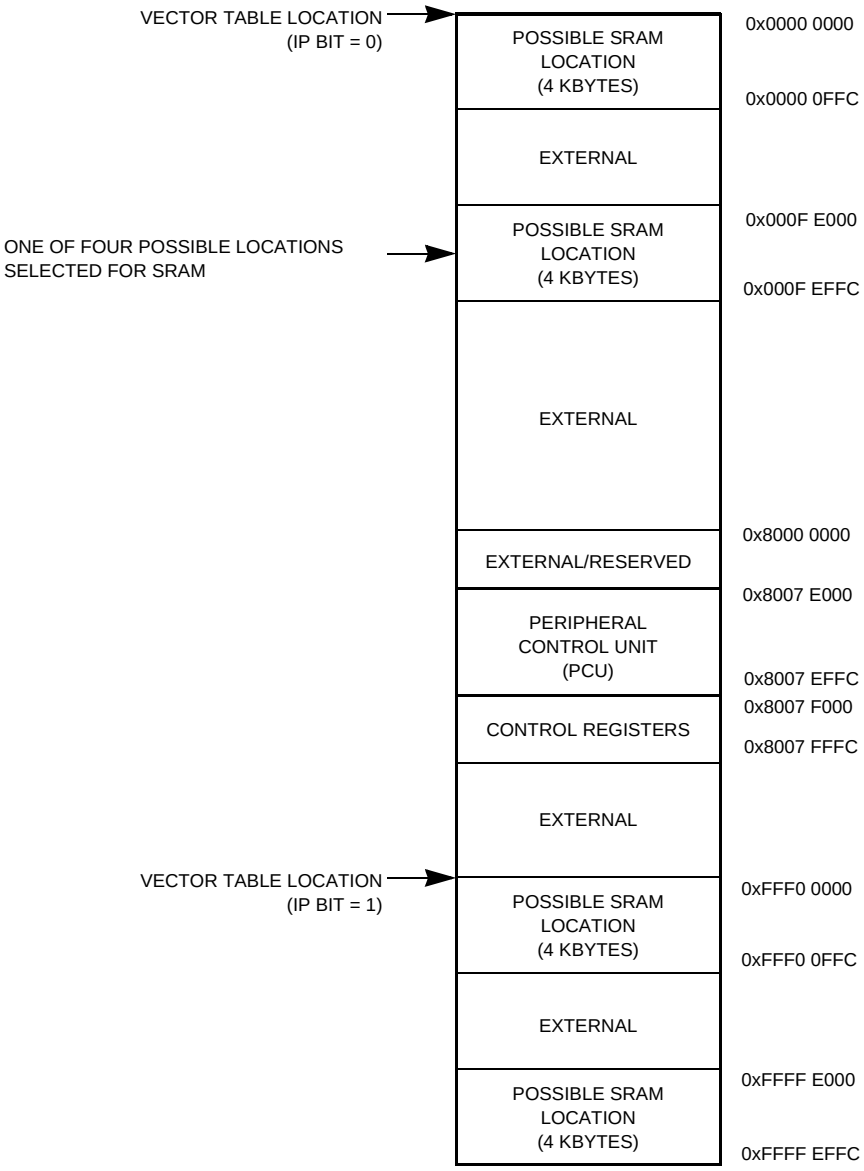


Figure 5-3 Placement of Internal Memory in Memory Map

5.3.3.2 Accesses to Unimplemented Internal Memory Locations

If an access is made to a location within the 2^n-sized memory block that is not implemented in any memory module on the chip, then the CPU takes a machine check exception.

5.3.3.3 Control Register Block

The internal control registers include all of the SIU registers and all of the configuration, control, and status registers of each module on the I-bus or L-bus. The internal control registers and the IMB2 are allocated a 512-Kbyte block from 0x8000 0000 to 0x8007 FFFF. The internal control registers always occupy the highest-numbered four Kbytes of this address range (0x8007 F000 to 0x8007 FFFF). The IMB2 modules (on

the MPC509, this includes only the PCU) are allocated the remainder of the 512-Kbyte block.

Unlike the memory arrays, the internal control registers and IMB2 modules cannot be disabled for development purposes. In addition, the IMB2 and control register block are only available in data space, not in instruction space. An instruction access to the address of a control register results in a data error on the I-bus, causing the internal $\overline{\text{TEA}}$ signal to be asserted.

5.3.3.4 Internal Memory Mapping Field (LMEMBASE)

The LMEMBASE field in the MEMMAP register maps the L-bus memory (i.e., the SRAM) to one of four possible locations in the memory map. The following table shows the meaning of the field. Note that these locations include the two possible locations for the CPU vector table. The address not given (start or end, depending upon the block) depends on the block size.

Table 5-4 Internal Memory Array Block Mapping

LMEMBASE	Block Placement
00	Starting Address: 0x0000 0000
01	Ending Address: 0x000F EFFC
10	Starting Address: 0xFFF0 0000
11	Ending Address: 0xFFFF EFFC

5.3.3.5 Memory Mapping Conflicts

Any access to a memory that does not exist causes the cycle to appear on the external bus. Because the MPC509 does not have an I-bus memory module, an access to I-bus memory is sent to the external bus, even if the I-bus memory enable (IEN) bit in the MEMBASE register is set.

5.3.4 Internal Cross-Bus Accesses

Each internal bus (I-bus and L-bus) has a master/slave interface in the SIU. The slave interface is used for accesses by the internal master (RCPU) to the external bus, to memory on the opposite bus (e.g., L-bus to I-bus access), or to SIU registers.

The SIU allows masters on either internal bus (I-bus or L-bus) to access slaves on the other internal bus. Accesses from one internal bus to resources on the other bus take at least three clocks, because of arbitration and cycle termination delays.

Instruction fetching from L-bus memory is intended primarily as a mechanism to allow a customer test program to be downloaded to on-chip RAM and executed. This is not a high-performance instruction fetching mechanism. Accesses from the I-bus to the L-bus are at least three clocks and not burstable.

Cross-bus accesses occur inside the SIU, consuming SIU resources during the access. Internal SIU registers are not available during cross-bus accesses. Internal-

to-external cycles are not pipelined with cross-bus accesses, nor are two consecutive cross-bus accesses pipelined.

Clearing the L-bus to I-bus cross-bus access (LIX) bit in the MEMMAP register disables data accesses to I-bus memory. This allows load/store data stored in a flash memory on the I-bus to be moved off-chip for development purposes. When this bit is cleared, L-bus to I-bus transactions are run externally.

5.3.5 Response to Freeze Assertion

The RCPU asserts the freeze signal to the rest of the MCU when one of the following conditions occurs:

- Debug mode is entered; or
- A software debug monitor program is entered as the result of an exception when the associated bit in the debug enable register (DER, SPR149) is set.

The following paragraphs explain how the assertion of the freeze signal affects the SIU. See SECTION 8 DEVELOPMENT SUPPORT for additional details on this signal.

5.3.5.1 Effects of Freeze and Debug Mode on the Bus Monitor

When the freeze signal is asserted and debug mode is disabled, the bus monitor is unaffected. This means that a software monitor must configure the bus monitor to provide protection from unterminated bus cycles that occur during debugging.

When the processor is in debug mode (debug mode is enabled and the freeze signal is asserted), the bus monitor is enabled. The bus monitor is also enabled when debug mode is enabled and a non-maskable breakpoint is asserted by the development port. These enables override the bus monitor enable bit (BME) in the bus monitor control register (BMCR) in the SIU. In both cases the bus monitor time-out period is whatever was programmed in the BMCR. This override allows an external development tool to retain control over the CPU in debug mode by not allowing an external bus cycle to hang the processor in an endless wait for a transfer acknowledge.

In addition, if the processor is executing normally and runs a bus cycle that is not terminated, a non-maskable breakpoint always gains control of the processor by terminating the bus cycle with the bus monitor so the processor can enter debug mode. In this case, the non-maskable breakpoint is not restartable. The processor takes the breakpoint before completing the prologue of the exception handler called as a result of the bus monitor.

5.3.5.2 Effects of Freeze on the Programmable Interrupt Timer (PIT)

When freeze is asserted and the SIU freeze bit (SIUFRZ) is set in the SIU module configuration register (SIUMCR), the PIT is disabled. This disable overrides the periodic interrupt enable bit (PIE) in the periodic interrupt control and select register (PICSR) in the SIU. This allows the count in the PIT to be preserved when execution stops.

5.3.5.3 Effects of Freeze on the Decrementer

When freeze is asserted and the SIUFRZ is set in the SIUMCR, the decrementer is disabled. This allows the value in the decrementer to be preserved when execution stops.

5.3.5.4 Effects of Freeze on Register Lock Bits

When freeze is asserted the lock bits in various registers can be set or cleared. This allows the protected configurations to be changed and then re-locked by a development support system.

5.4 External Bus Interface

The external bus interface (EBI) interfaces the external bus (E-bus) with the two internal buses (I-bus and L-bus). The E-bus is synchronous and supports pipelined and burst transfers. Signals driven onto the E-bus are required to meet the set-up and hold times relative to the rising edge of the bus clock. The bus has the ability to support multiple masters, but its protocol is optimized for a single-processor environment.

5.4.1 Features

- No external glue logic required for a simple system.
- Supports different memory (SRAM, EEPROM) types: asynchronous, synchronous, pipelineable, burstable.
- Fast (one-clock) arbitration possible.
- Bus is synchronous — all signals are referenced to the rising edge of the bus clock.
- 32-bit data bus, 32-bit address bus with byte enables.
- Compatible with PowerPC architecture.
- Protocol allows wait states to be inserted during the data phase and supports early burst termination.
- Supports both 16-bit and 32-bit port sizes.
- Bus electrical specification minimizes system power consumption.

5.4.2 External Bus Signals

Table 5-5 summarizes the E-bus signals. The following abbreviations are used in this table:

M = Bus master
S = Slave device
A = Central bus arbiter
T = Bus watchdog timer
X = Any device on the system

Table 5-5 EBI Signal Descriptions

Mnemonic	Direction	Description
Address Phase Signals		
ADDR[0:29]	M → S	32-bit address bus. Least significant two bits (ADDR[30:31]) are not pinned out; they can be determined from the $\overline{\text{BE}}$[0:3] pins. ADDR0 is the most significant bit. Address bus is driven by the bus master to index the bus slave.
$\overline{\text{TS}}$	M → S	Transfer start. This address control signal is asserted for one clock cycle at the beginning of a bus access by the bus master.
$\overline{\text{WR}}$	M → S	Write/read. When this address attribute is asserted, a write cycle is in progress. When negated, a read cycle is in progress. For use of $\overline{\text{WR}}$ during show cycles, refer to **SECTION 8 DEVELOPMENT SUPPORT**.
$\overline{\text{BE}}$[0:3]	M → S	Byte enables. These address attribute signals indicate which byte within a word is being accessed. External memory chips can use these signals to determine which byte location is enabled. **Table 5-7** shows the encodings for these pins during accesses to 32-bit and 16-bit ports. A device need only observe the byte enables corresponding to the data lanes on which it resides. For example, a device on data lane DATA[0:7] should use $\overline{\text{BE}}$0, and a device on DATA[0:15] should use $\overline{\text{BE}}$[0:1]. The device should not respond to the bus cycle unless its byte enables are active at the start of the bus cycle.
AT[0:1]	M → S	Address types. These address attribute signals define addressed space as user or supervisor, data or instruction. Refer to **Table 5-6** for encodings. These signals have the same timing as ADDR[0:29].
CT[0:3]	M → S	Cycle type signals. These address attribute signals indicate what type of bus cycle the bus master is initiating. Used for development support. Refer to **Table 5-14** for encodings.
$\overline{\text{BURST}}$	M → S	Burst cycle. This address attribute indicates that the transfer is a burst transfer. If a burst access is burst-inhibited by the slave, the $\overline{\text{BURST}}$ pin is driven during each single-beat (decomposed) cycle.
$\overline{\text{AACK}}$	S → M	Address acknowledge. When asserted, indicates the slave has received the address from the bus master. This signal terminates the address phase of a bus cycle. When the bus master receives this signal from the slave, the master can initiate another address transfer. This signal must be asserted at the same time or prior to $\overline{\text{TA}}$ assertion.
$\overline{\text{ARETRY}}$	S, A → M	Address retry. This is an address phase termination signal. It is designed to resolve deadlock cases on hierarchical bus structures or for error-correcting memories. $\overline{\text{ARETRY}}$ assertion overrides $\overline{\text{AACK}}$ assertion and causes the SIU to re-arbitrate and to re-run the bus cycle.
$\overline{\text{BI}}$	S → M	Burst inhibit. When asserted, indicates the slave does not support burst mode. Sampled at same time as $\overline{\text{AACK}}$. If $\overline{\text{BI}}$ is asserted, the SIU transfers the burst data in multiple cycles and increments the address for the slave in order to complete the burst transfer.
Data Phase Signals		
DATA[0:31]	M ↔ S	32-bit data bus. DATA0 is most significant bit; DATA31 is the least significant bit. During small-port accesses, data resides on DATA[0:15].

Table 5-5 EBI Signal Descriptions (Continued)

Mnemonic	Direction	Description
$\overline{\text{BDIP}}$	M → S	Burst data in progress. This signal is asserted at the beginning of a burst data phase and is negated during the last beat of a burst. The master uses this signal to give the slave advance warning of the remaining data in the burst. This can also be used for an early termination of a burst cycle. When the LST bit in the SIUMCR is asserted, the $\overline{\text{BDIP}}$ pin uses $\overline{\text{LAST}}$ timing. If the LST bit is negated, the $\overline{\text{BDIP}}$ pin uses $\overline{\text{BDIP}}$ timing. Refer to **5.5.16.6 Synchronous Burst Interface** for more information.
$\overline{\text{TA}}$	S → M	Transfer acknowledge. When asserted, indicates the slave has received the data during a write cycle or returned the data during a read cycle. During burst cycles, the slave asserts this signal with every data beat returned or accepted.
$\overline{\text{TEA}}$	T, S → M	Transfer error acknowledge. Assertion of $\overline{\text{TEA}}$ indicates an error condition has occurred during the bus cycle, and the bus cycle is terminated. This signal overrides any other cycle termination signals (e.g., $\overline{\text{TA}}$ or $\overline{\text{ARETRY}}$).
$\overline{\text{DS}}$	M → S	Data strobe. Asserted by EBI at the end of a chip-select-controlled bus cycle. Asserted after the chip-select unit asserts the internal $\overline{\text{TA}}$ or $\overline{\text{TEA}}$ signal or the bus monitor timer asserts the internal $\overline{\text{TEA}}$ signal. Also asserted at the end of a show cycle.
Arbitration		
$\overline{\text{BR}}$	M → A	Bus request. When asserted, indicates the potential bus master is requesting the bus. Each master has its own bus request signal.
$\overline{\text{BG}}$	A → M	Bus grant. When asserted by bus arbiter, the bus is granted to the bus master. Each master has its own bus grant signal.
$\overline{\text{BB}}$	M → M, A	Bus busy. Asserted by current bus master to indicate the bus is currently in use. Prospective new master should wait until the current master negates this signal.
Miscellaneous		
$\overline{\text{CR}}$	X → M	Cancel reservation. Each PowerPC CPU has its own $\overline{\text{CR}}$ signal. This signal shows the status of any outstanding reservation on the external bus. When asserted, $\overline{\text{CR}}$ indicates that there is no outstanding reservation. This is a level signal.
$\overline{\text{RESET}}$	Source → M	This input-only signal resets the entire MCU. While $\overline{\text{RESET}}$ is asserted, the MCU asserts the $\overline{\text{RESETOUT}}$ signal.
$\overline{\text{RESETOUT}}$	M → S	Reset output. This output-only signal indicates that the MCU is in reset. When asserted, instructs all devices monitoring this signal to reset all parts within themselves that can be reset by software.
CLKOUT	Source → M, S	Continuously-running clock. All signals driven on the E-bus must be synchronized to the rising edge of this clock.

Table 5-6 Address Type Encodings

AT0	AT1	Address Space
0	0	User data space
0	1	User instruction space
1	0	Supervisor data space
1	1	Supervisor instruction space

Table 5-7 Byte Enable Encodings

Byte Enable	Use During 32-Bit Port Access	Use During 16-Bit Port Access
$\overline{BE0}$	Byte Enable for DATA[0:7]	Byte Enable for DATA[0:7]
$\overline{BE1}$	Byte Enable for DATA[8:15]	Byte Enable for DATA[8:15]
$\overline{BE2}$	Byte Enable for DATA[16:23]	ADDR30
$\overline{BE3}$	Byte Enable for DATA[24:31]	0 = Operand size is word 1 = Operand size is byte or half word

5.4.3 Basic Bus Cycle

The basic external bus cycle consists of two phases: the address phase and the data phase. If the external bus is not available when the SIU is ready to start an external cycle, a bus arbitration phase is also required.

External bus cycles can be single or multiple (burst) data cycles. Burst cycles normally have four data words associated with the cycle. Refer to 5.4.6 Burst Cycles for information on burst cycles.

5.4.3.1 Read Cycle Flow

Figure 5-4 is a flow diagram of a single read cycle on the external bus.

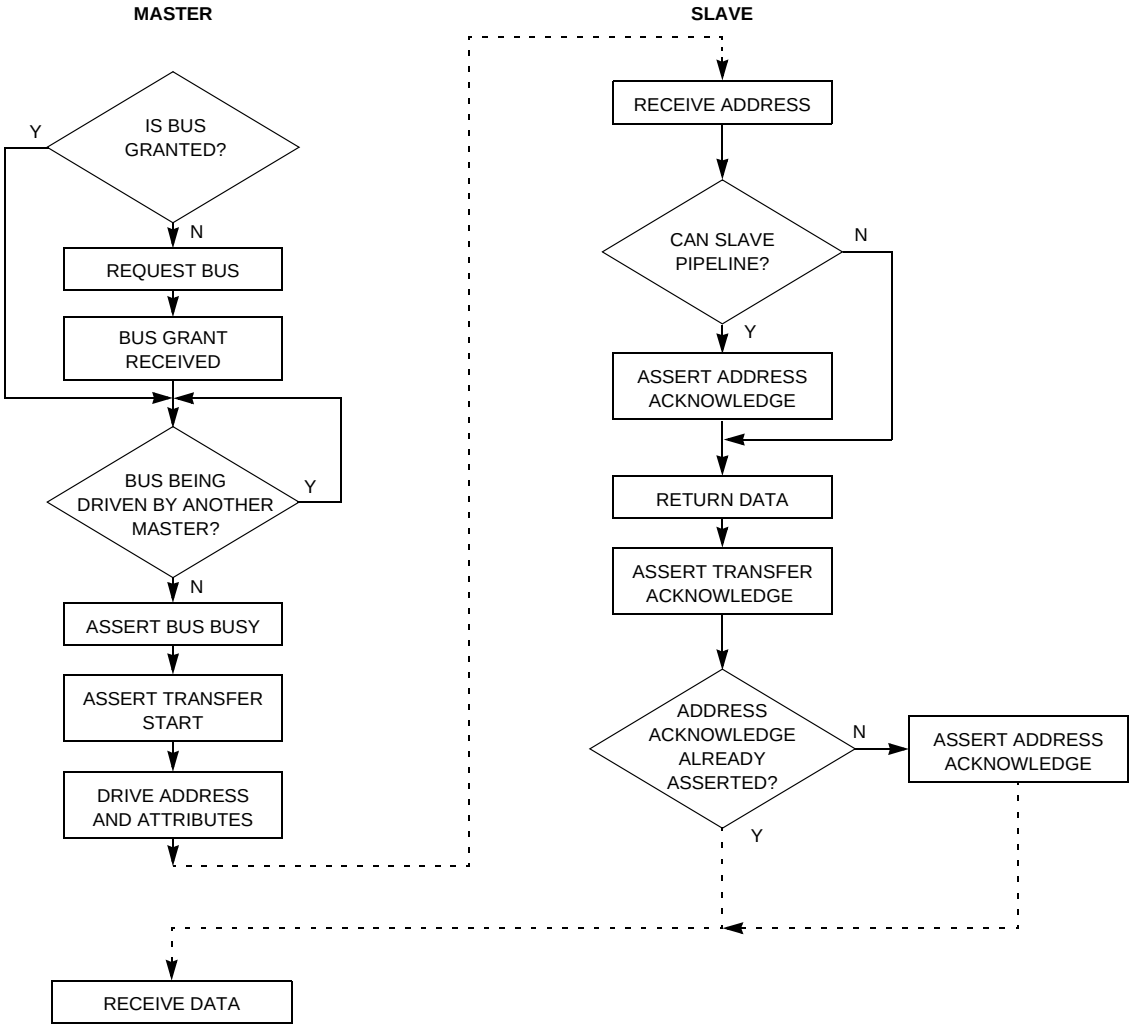


Figure 5-4 Flow Diagram of a Single Read Cycle

Figure 5-5 is a simplified timing diagram of a read cycle.

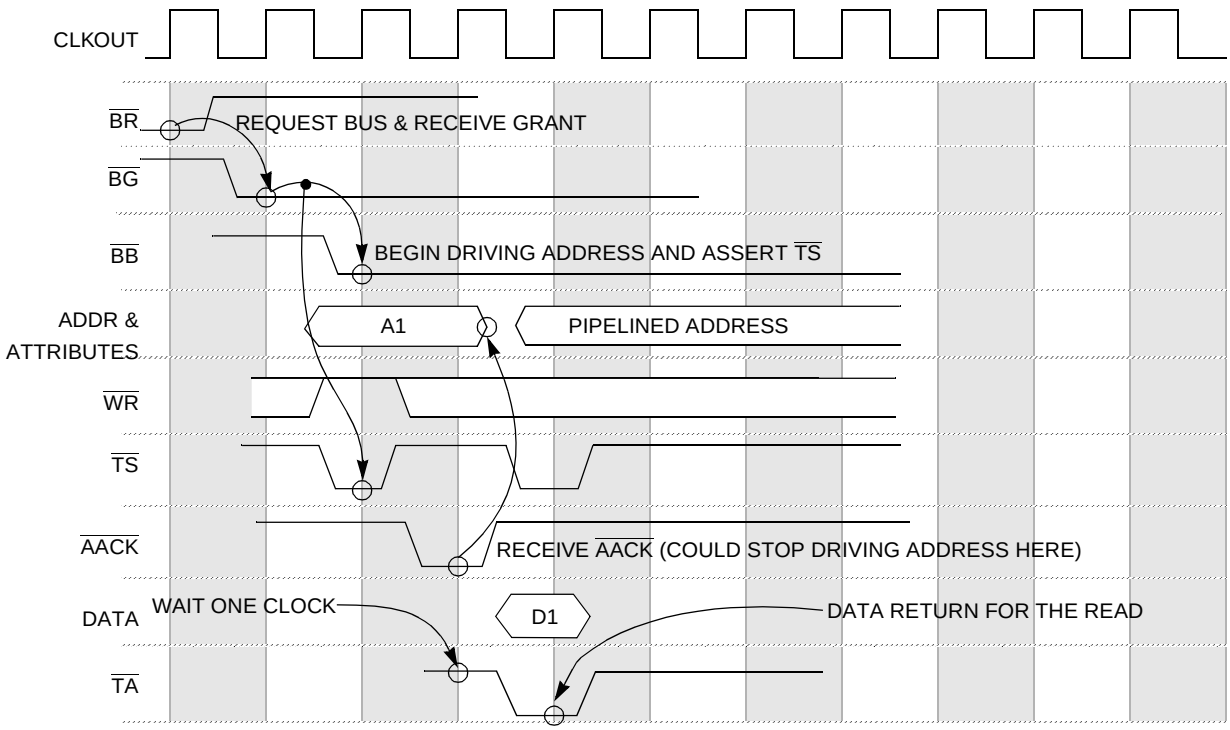


Figure 5-5 Example of a Read Cycle

5.4.3.2 Write Cycle Flow

Figure 5-6 is a flow diagram of a single write cycle on the external bus.

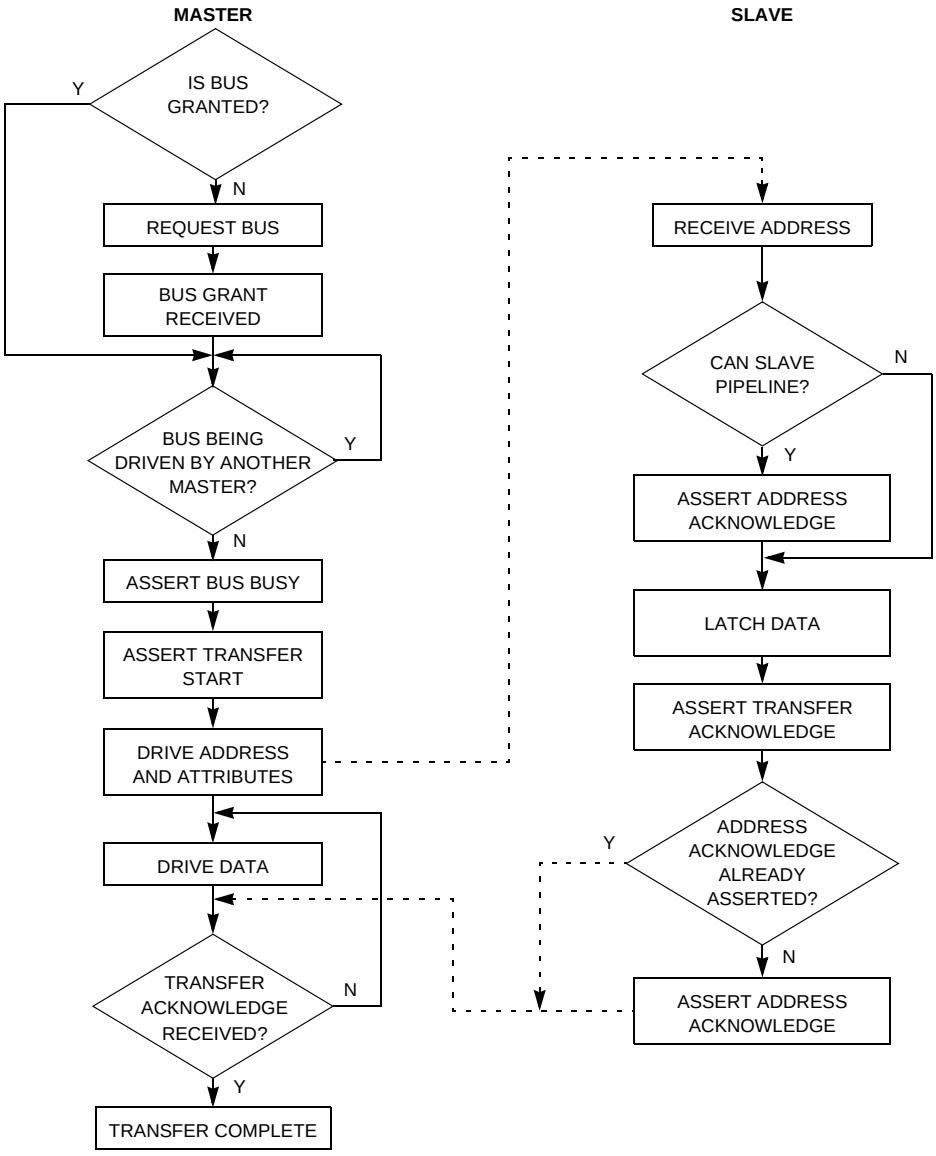


Figure 5-6 Flow Diagram of a Single Write Cycle

5.4.4 Basic Pipeline

The EBI supports a maximum pipeline depth of two; that is, up to two addresses can be active on a bus at the same time. Pipelining is simplified by using SIU chip selects, since chip-select registers can have the information about the characteristics of each external memory. 5.5 Chip Selects discusses which cycles can be pipelined.

The EBI supports pipelined accesses for read cycles only. A write bus cycle starts only when the pipe depth is zero, or would have gone to zero if a new cycle had not started. A read bus cycle will start when the pipe depth is either zero or one, or would have gone to one if a new cycle had not started.

An example of bus pipelining is shown in **Figure 5-7**.

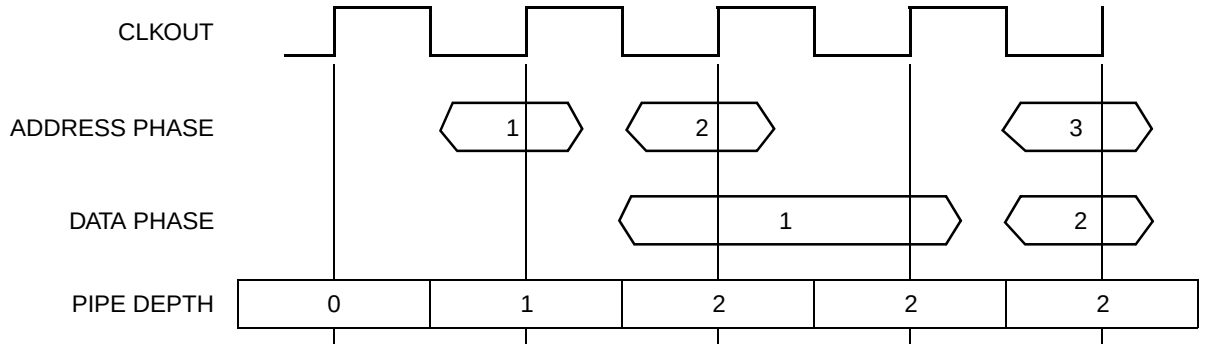


Figure 5-7 Example of Pipelined Bus

Figure 5-8 illustrates a write access followed by two read accesses on the external bus.

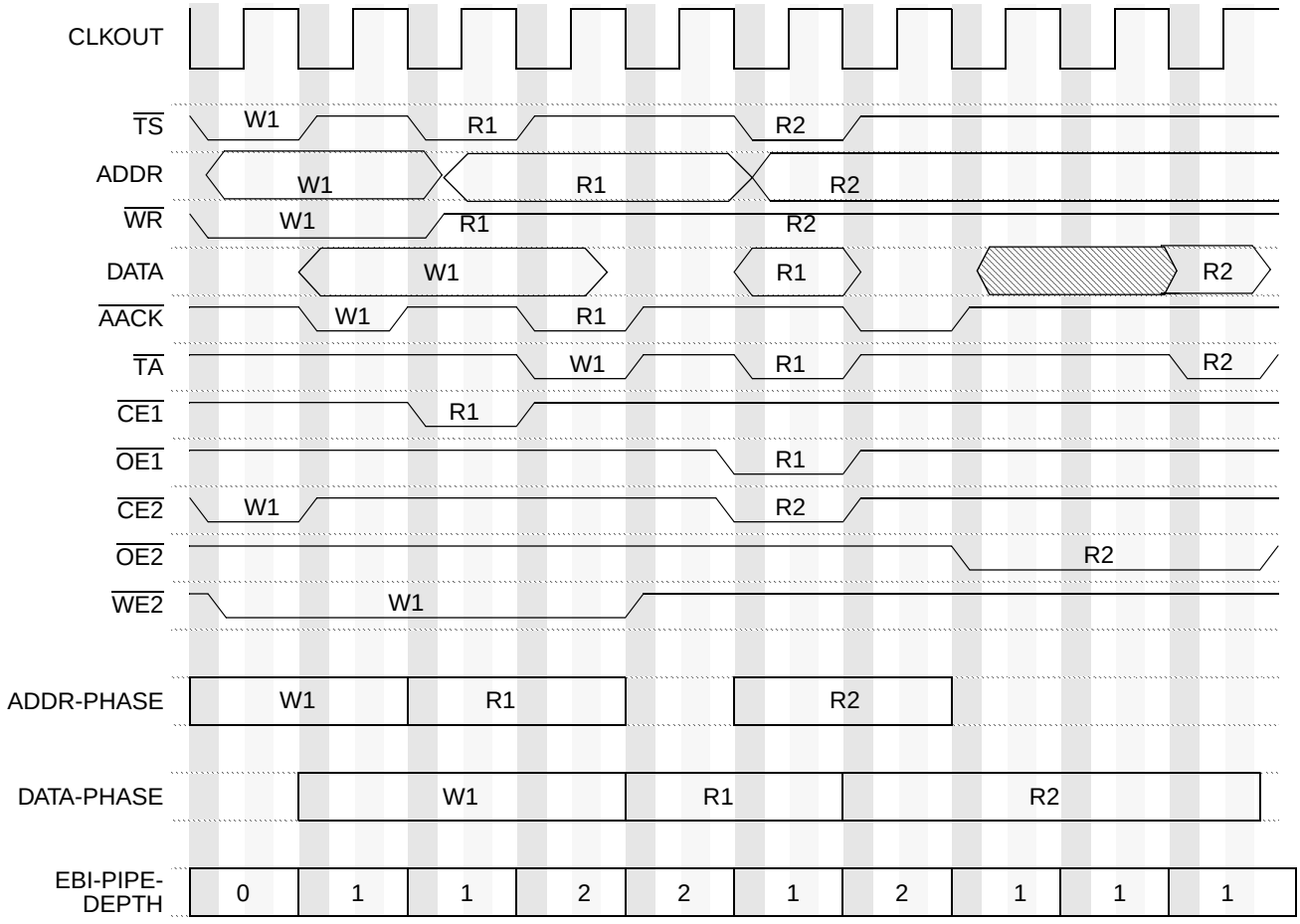


Figure 5-8 Write Followed by Two Reads on the E-Bus (Using Chip Selects)

5.4.5 Bus Cycle Phases

The following paragraphs describe the three bus cycle phases: arbitration phase, address phase, and data phase. Note that there is no separate arbitration for the address and data buses.

5.4.5.1 Arbitration Phase

The SIU supports multiple masters but is optimized for single-master systems. Each master must have bus request, bus grant, and bus busy signals. Arbitration signals of the masters feed into a central arbiter for arbitration.

Before the SIU can start an external cycle, it must have a qualified bus grant. A qualified bus grant occurs when the external arbiter asserts $\overline{BG}$ (bus grant) and the previous bus master negates $\overline{BB}$ (the bidirectional bus busy signal). This means that no other master is currently running a cycle on the external bus. If the SIU is ready to start an external cycle and it does not have a qualified bus grant, then it asserts $\overline{BR}$ (bus request) until it receives the qualified bus grant. Once the SIU receives a qualified bus grant, it asserts $\overline{BB}$ and begins the address phase of the cycle.

A word-aligned access to a 16-bit port results in two bus cycles. To preserve word coherency, the SIU does not release the bus between these two cycles.

The external arbiter can park the bus by keeping $\overline{BG}$ asserted. Single-master systems should tie this signal low permanently, or configure the pin as a port pin, which has the same effect. Each potential master has its own $\overline{BG}$ input signal.

5.4.5.2 Address Phase

Once the SIU has a qualified bus grant, it asserts $\overline{BB}$ and starts an address phase. The SIU drives a new address at the start of the address phase and maintains it on the pins throughout the address phase.

The signals shown in **Table 5-8** are driven at the start of the address phase.

Table 5-8 Signals Driven at Start of Address Phase

Mnemonic	Signal Name	Type
ADDR[0:29]	Address bus	Address bus
$\overline{TS}$	Transfer start	Control
$\overline{WR}$	Write/read	Address attribute
$\overline{BE[0:3]}$	Byte enables	Address attribute
AT[0:1]	Address type	Address attribute
CT[0:3]	Cycle type	Address attribute
$\overline{BURST}$	Burst	Address attribute

$\overline{TS}$ is a control signal that is valid for only one clock cycle at the start of the address phase. The address attributes listed in **Table 5-8** are updated at the start of the address phase and are maintained until the start of the next address phase.

The address phase is the period of time from the assertion of $\overline{TS}$ until the address phase is terminated by one of the following signals:

- Address acknowledge ($\overline{AACK}$)
- Address retry ($\overline{ARETRY}$)
- Transfer error acknowledge ($\overline{TEA}$)

If the external memory is under chip-select control and the chip selects are enabled to return handshakes, then the chip selects normally generate $\overline{AACK}$ internally. However, if the external $\overline{AACK}$ pin is asserted before the chip select module generates the signal, the chip select module accepts the external pin information and does not generate the $\overline{AACK}$ signal internally.

Burst inhibit ($\overline{BI}$) is sampled when $\overline{AACK}$ is asserted. $\overline{BI}$ is asserted by the slave to indicate to the SIU that the addressed device does not have burst capability. Refer to 5.4.6.2 Burst Inhibit Cycles for more information.

$\overline{ARETRY}$ and $\overline{TEA}$ can also be used to terminate the address phase. Refer to **5.4.10 Address Retry** and 5.4.11 Transfer Error Acknowledge Cycles for more information.

5.4.5.3 Data Phase

If the pipe depth before a cycle starts is zero (or would have gone to zero if the new cycle had not started), then the data phase always starts one clock cycle after the address phase starts. If there is a previous data phase in progress one clock after an address phase starts, then the data phase for that address phase starts as soon as the previous data phase completes. The data phase completes when it is terminated by $\overline{TA}$ or $\overline{TEA}$. If the cycle is a burst cycle, then multiple $\overline{TA}$ assertions are required to terminate the data phase.

During the data phase, the following signals are used:

- DATA[0:31]
- Burst data in progress ($\overline{BDIP}$)

The data phase can be terminated with either of the following signals:

- Transfer acknowledge ($\overline{TA}$)
- Transfer error acknowledge ($\overline{TEA}$)

$\overline{AACK}$ and $\overline{TA}$ are required for every cycle. If, under some error condition, the slave asserts $\overline{TA}$ but not an $\overline{AACK}$, the SIU does not recover from this error condition.

If the external memory is under chip-select control and the chip selects are programmed to return handshakes (ACKEN = 1 in the chip-select option registers), then the chip selects return $\overline{TA}$ unless the external $\overline{TA}$ pin is asserted first. In that case, the chip select module accepts the external pin information and does not generate $\overline{TA}$ internally.

A bus timer or system address protection mechanism can assert transfer error acknowledge ($\overline{TEA}$) to terminate the data phase when a bus error condition is encountered. Refer to 5.4.11 Transfer Error Acknowledge Cycles for further information.

The EBI asserts the data strobe ($\overline{DS}$) signal at the end of a chip-select controlled bus cycle, provided that either

- The chip select unit asserts the internal $\overline{TA}$ signal; or
- The bus monitor timer asserts the internal $\overline{TEA}$ signal.

$\overline{DS}$ is not asserted, however, if $\overline{TA}$ or $\overline{TEA}$ is asserted externally, even if $\overline{TA}$ or $\overline{TEA}$ is simultaneously asserted internally.

In addition to being asserted at the end of the bus cycles mentioned above, $\overline{DS}$ is asserted at the end of a show cycle.

5.4.6 Burst Cycles

Burst cycles allow the fast transfer of instructions over the bus. The MPC509 supports fixed-length burst cycles of four beats for instruction reads only. Burst cycles can be terminated early with the $\overline{BDIP}$ signal.

Burst reads on the external bus do not start until the internal data bus is available. For example, when the SIU starts a burst read and does not have L-bus data bus grant because there is an L-bus cycle in progress (an IMB2 access), then the SIU holds off the burst read until it can guarantee that it will have the internal bus grant.

At the start of a burst transfer, the master drives the address, the address attributes, transfer start, and the $\overline{BURST}$ signal to indicate a burst transfer. If the slave can perform burst transfers, it negates the burst inhibit signal ($\overline{BI}$). If the slave does not support burst transfers, it asserts $\overline{BI}$.

An example of a burst read on the external bus is shown in **Figure 5-9**.

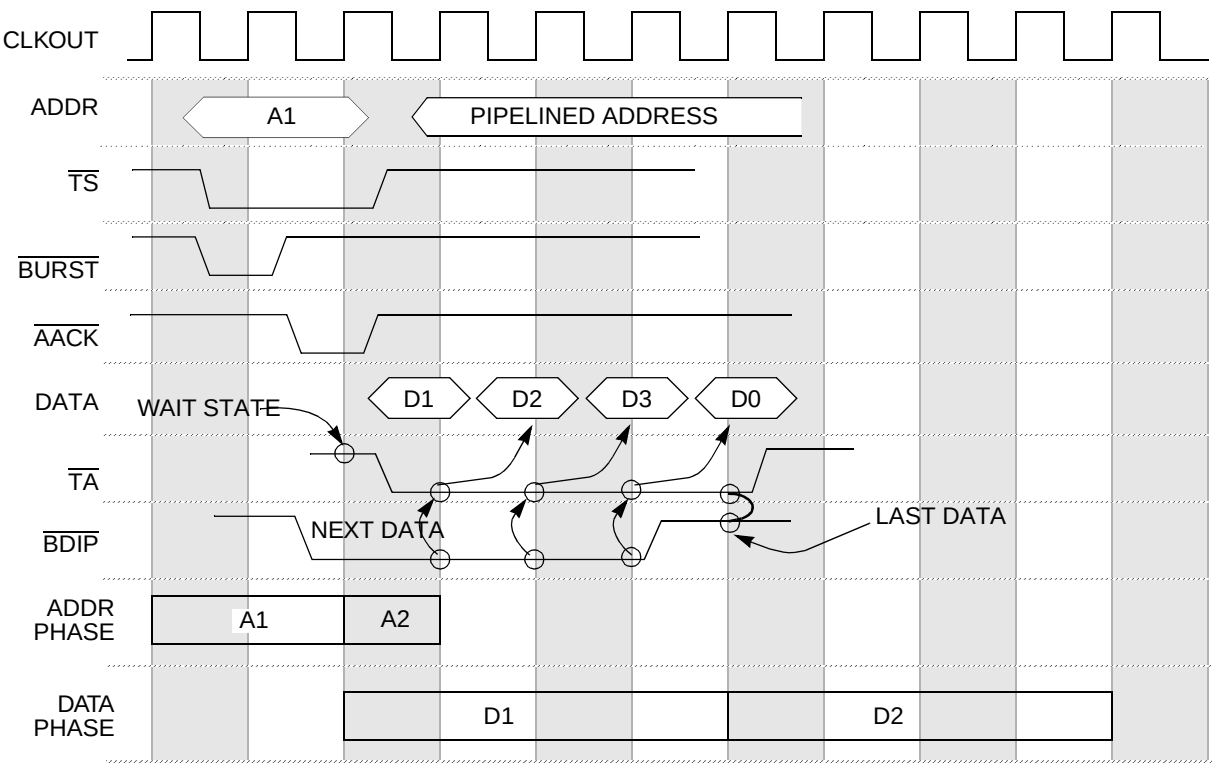


Figure 5-9 External Burst Read Cycle

5.4.6.1 Termination of Burst Cycles

During the data phase of a burst read cycle, the master receives data from the addressed slave. The EBI asserts the $\overline{\text{BDIP}}$ signal at the beginning of a burst data phase and negates $\overline{\text{BDIP}}$ during the last beat of a burst. The slave device stops driving new data after it receives the negation of $\overline{\text{BDIP}}$ at the rising edge of the clock.

The EBI can terminate a burst cycle early by asserting the $\overline{\text{BDIP}}$ pin. Early termination is used for a word aligned (not double-word aligned) burst to a small port.

The LST bit in the SIU module configuration register (SIUMCR) determines the timing used for the $\overline{\text{BDIP}}$ pin. If LST is cleared, then the pin uses $\overline{\text{BDIP}}$ timing. If the bit is set, the pin uses $\overline{\text{LAST}}$ timing. The timing protocol of the external memory determines whether this bit should be set or cleared. Refer to 5.5.16.6 Synchronous Burst Interface for examples of both types of timing.

Burst cycles can also be terminated with the $\overline{\text{ARETRY}}$ signal. Refer to 5.4.10 Address Retry for more information.

5.4.6.2 Burst Inhibit Cycles

Burst inhibit ($\overline{\text{BI}}$) is an address phase termination attribute that is sampled when $\overline{\text{AACK}}$ is asserted. The slave asserts $\overline{\text{BI}}$ to indicate to the SIU that the addressed device does not have burst capability. If this signal is asserted, the SIU transfers the data in multiple cycles and increments the address for the slave in order to complete the burst transfer.

A burst can only be burst inhibited until the first data is acknowledged ($\overline{TA}$ asserted). Since $\overline{BI}$ is not sampled until $\overline{AACK}$ is asserted, $\overline{AACK}$ must be asserted before or at the same time as $\overline{TA}$. Otherwise, the $\overline{BI}$ pin is never sampled.

The EBI supports three types of memory. These memory types use the $\overline{AACK}$ and $\overline{BI}$ signals as follows:

- A simple asynchronous memory keeps $\overline{AACK}$ negated to keep the address valid. The device can assert $\overline{BI}$ along with $\overline{AACK}$ or before $\overline{AACK}$ and with the first $\overline{TA}$.
- A synchronous, pipelineable, non-burstable memory returns $\overline{AACK}$ as soon as it is ready to receive the next address and asserts $\overline{BI}$.
- A burstable memory returns $\overline{AACK}$ and negates $\overline{BI}$ along with $\overline{AACK}$ or before $\overline{AACK}$.

CAUTION

If a memory region is under chip-select control, the chip-select unit generates $\overline{BI}$ internally during burst accesses to interface types that do not support burst accesses. It is recommended that the $\overline{BI}$ pin not be asserted during accesses to memory regions controlled by chip selects; instead, the chip-select unit will generate the $\overline{BI}$ signal internally when appropriate.

5.4.7 Decomposed Cycles and Address Wrapping

If a burst cycle initiated by one of the internal buses is burst inhibited by the chip selects or by the pins, the EBI decomposes this cycle into four single beat accesses. The EBI increments the address internally and sends the received data (from the four single external reads) back to the originating bus as a burst transaction.

The EBI breaks a burst access to a device with a 16-bit port into two or three cycles, depending on the starting address (or eight cycles if $\overline{BI}$ is asserted) and increments the address appropriately. Examples of burst access address wrapping are shown in **Table 5-9**. If a burst access to a device with a 16-bit port is burst inhibited by the chip selects or by external memory asserting the $\overline{BI}$ pin, the EBI decomposes the transfer into eight single-beat accesses.

Depending on the starting address for the burst access and whether the address is word- or double-word-aligned, the EBI wraps the address to fetch the correct data from memory (four words or eight half words).

If the EBI receives $\overline{TEA}$ for one part of a decomposed cycle, it generates $\overline{TEA}$ internally for the remaining parts of the decomposed cycle as well.

Table 5-9 Burst Access Address Wrapping

Port Size	Starting Address ADDR[28:30]	Burst Address Wrapping ADDR[28:30]	Half-Word/Word Boundary Address
16 bit	000	000 (Starting address) 001 010 011 100 101 110 111	Double word boundary, Two bursts of four beats each
16 bit	010	010 (Starting address) 011 100 101 110 111 000 001	Odd word boundary, One burst of two beats One burst of four beats One burst of two beats The master (the EBI) terminates the two-beat-burst with $\overline{\text{BDIP}}$.
32 bit	000	000 (Starting address) 010 100 110	Quad word boundary One burst of four beats
32 bit	100	100 (Starting address) 110 000 010	Double (non-quad) word boundary One burst of four words (word 3-4-1-2)

5.4.8 Preventing Speculative Loads

The SIU can be programmed to prevent speculative loads to a selected external region. A speculative operation is one which the hardware performs out of order and which it otherwise might not perform, such as executing an instruction following a conditional branch.

Note that the MPC509 never performs speculative stores; it always waits until the instruction is ready to be retired before writing to external memory. Refer to the *RCPU Reference Manual* (RCPURM/AD) for more information.

When data loaded speculatively from RAM later needs to be discarded, this does not ordinarily present a problem. For example, a load instruction that follows a floating-point instruction in the instruction stream could begin execution before the floating-point instruction is retired. If the floating-point instruction generates an exception, the result of the load instruction is discarded, the exception is processed, and the processor automatically re-issues the load instruction.

However, if the address of the speculative load represents a FIFO device, the speculatively loaded data is lost when the exception is processed, and the re-issued load instruction loads the next data item in the queue. Preventing speculative loads is necessary to prevent this scenario from occurring.

As another example, a memory-mapped I/O device could have a status register that is updated whenever its data register is read. If the data register is read speculatively, the status register is updated, even if the result of the read is subsequently discarded (for example, if a previously issued instruction generates an exception).

Two registers and their associated logic allow a block ranging in size from 1 Kbyte to 64 Kbytes, or parts of the block, to be protected from speculative accesses. The most significant 22 bits of the address of each L-bus cycle are bitwise compared to the non-speculative base address register (SPECADDR), with each result bit equal to one if the bits match. A bitwise OR is performed on the lower six bits of the resulting word with the mask in the non-speculative mask register (SPECMASK). If all six result bits are ones and the upper 16 result bits are all ones, then speculative accesses are prevented during the current cycle.

SPECADDR — Non-Speculative Base Address Register **0x8007 FC24**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
BASE ADDRESS																						RESERVED									
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5-10 SPECADDR Bit Settings

Bit(s)	Name	Description
0:21	BASE ADDRESS	22-bit base address of region protected from speculative loads.
22:31	—	Reserved

SPECMASK — Non-Speculative Mask Register **0x8007 FC28**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED																MASK						RESERVED									
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5-11 SPECMASK Bit Settings

Bit(s)	Name	Description
0:15	—	Reserved
16:21	MASK	Six-bit mask that specifies which block or blocks within region specified in SPECMASK register are actually protected from speculative accesses.
22:31	—	Reserved

Because the mask register can contain any six-bit value, the mask can allow for blocks of up to 64 Kbytes, and it can provide for smaller blocks of memory that alternately allow and prevent speculative loads. **Table 5-12** provides several examples. In these examples, the protected blocks are those that match the value in the SPECADDR register.

Table 5-12 Example Speculative Mask Values

Mask Value (Binary)	Protected Region
000000	1-Kbyte block
111111	64-Kbyte block
111110	Every second 1-Kbyte block within a 64-Kbyte block
111101	Every second 2-Kbyte block within a 64-Kbyte block
110011	Every fourth 4-Kbyte block within a 64-Kbyte block
100011	Every eighth 4-Kbyte block within a 64-Kbyte block
010000	Every sixteenth 1-Kbyte block within a 32-Kbyte block

Protection from speculative loads can be disabled by setting the SPECADDR register to an internal or unimplemented address range.

5.4.9 Accesses to 16-Bit Ports

The EBI supports accesses to 16-bit ports on the external bus. 16-bit port size is a chip-select option; the access must be initiated using one of the chip selects. A 16-bit port must connect its data lines to the upper 16 bits of the external data bus (DATA[0:15]).

During an access to a 16-bit port, byte enable signals $\overline{\text{BE[0:1]}}$ are used to indicate which bytes of the half-word are being accessed, and the $\overline{\text{BE2}}$/ADDR30 pin functions as ADDR30 (active high). $\overline{\text{BE3}}$ is asserted (low) if the operand size is a word and negated (high) if the operand size is a byte or half-word. This encoding is needed to maintain coherency of word accesses on the external bus.

Table 5-13 shows how EBI decomposes the word, half word, and byte accesses to a 16-bit port. For each combination of operand size and address (placement on the internal L-data bus), the table shows the values of $\overline{\text{BE[0:3]}}$ and indicates which bytes of the operand are accessed and where these bytes are placed on the E-bus.

Table 5-13 EBI Read and Write Access to 16-Bit Ports

Operand Size	Internal L-Bus ADDR[30:31]	Internal L-Bus Data Bytes Accessed	$\overline{\text{BE[0:3]}}$	Placement of L-Bus Data Bytes On E-Bus	
				E-Bus DATA[0:7]	E-Bus DATA[8:15]
Byte	00	Byte 0	0101	Byte 0	X
Byte	01	Byte 1	1001	X	Byte 1
Byte	10	Byte 2	0111	Byte 2	X
Byte	11	Byte 3	1011	X	Byte 3
Half Word	00	Bytes 0 to 1	0001	Byte 0	Byte 1
Half Word	10	Bytes 2 to 3	0011	Byte 2	Byte 3
Word	00	Bytes 0 to 3	0000 0010	Byte 0 Byte 2	Byte 1 Byte 3

All transfer errors that occur during a small port access terminate the cycle currently in progress. If an error occurs during any part of a word access to a small port, the cur-

rent access is terminated. Subsequent bus cycles of the small port access will continue, but TEA will be asserted internally with each beat.

5.4.10 Address Retry

Address retry (ARETRY) can be used to terminate the address phase. Assertion of ARETRY causes the master to re-arbitrate and to re-run the bus cycle. The address retry mechanism can be used to break deadlocks between the E-bus and the user's on-board I/O bus (for example, a PC/AT or VME bus in a hierarchical bus system). The address retry mechanism can also be used for error correction purposes.

After receiving TS, the external device must wait at least one clock cycle before asserting ARETRY. Note that this could be an issue at low frequencies — it is possible for an external device to receive TS, decode the address, and assert ARETRY in the same clock cycle. This is illegal.

The SIU does not guarantee word coherency if ARETRY is asserted for the second half of a word cycle of a decomposed word transfer. The external arbiter is responsible for maintaining the coherency by monitoring the byte enable lines and making sure that no other master updates that location until the retried cycle is successfully completed.

Note that BB is not negated until the second clock cycle after ARETRY assertion.

CAUTION

TA or TEA must not be asserted during a cycle in which ARETRY is asserted. If TA is asserted for any part of a burst cycle, ARETRY must not be asserted at any time during the cycle; if ARETRY is asserted during a burst cycle, it must be asserted before the first beat is terminated with TA.

5.4.11 Transfer Error Acknowledge Cycles

A bus timer or system address protection mechanism can assert transfer error acknowledge (TEA) to terminate the data phase when one of the following types of bus error conditions is encountered:

- Write to a read-only address space
- Access to a non-existent address

TEA assertion overrides the assertion of TA. Assertion of TEA causes the processor to enter the checkstop state, enter debug mode, or process a machine check exception. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details.

CAUTION

TEA must not be asserted during a cycle in which ARETRY is asserted.

If the address phase corresponding to the current data phase is still outstanding (AACK has not yet been asserted), TEA terminates both the address and the data

phase. That is, the EBI generates $\overline{\text{AACK}}$ and $\overline{\text{TA}}$ internally and generates an internal error signal for that cycle. If $\overline{\text{AACK}}$ has already been asserted externally, the EBI generates $\overline{\text{TA}}$ but not $\overline{\text{AACK}}$ internally and generates an internal error signal for that cycle.

All transfer errors that occur during an access to a 16-bit port terminate the cycle currently in progress. If an error occurs during any part of a word access to a 16-bit port, the current access is terminated. Subsequent bus cycles of the small port access will continue, but $\overline{\text{TEA}}$ will be asserted internally with each beat.

All illegal accesses to internal registers are terminated with a data error, causing the bus monitor to assert the internal $\overline{\text{TEA}}$ signal. Accesses to unimplemented internal memory locations and privilege violations (user access to supervisor register or write to read-only location or a write to register which is locked) also cause the bus monitor to assert the internal $\overline{\text{TEA}}$ signal.

Note that the chip-select module can also assert the internal $\overline{\text{TEA}}$ signal. Refer to **5.5.7 Access Protection** for more information.

5.4.12 Cycle Types

The cycle type pins (CT[0:3]) are address-phase signals that provide information about the type of internal or external bus cycle in progress. These pins can be used by an external development system to construct a program trace.

Table 5-14 summarizes the cycle type encodings. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details on how a development system can use the information provided by these pins.

Table 5-14 Cycle Type Encodings

CT[0:3]	Cycle Type	Description
0000	Normal bus cycle	This is a normal external bus cycle. Both the address and data phase are seen on the external bus. This cycle requires an $\overline{\text{AACK}}$ and a $\overline{\text{TA}}$ signal. This cycle type is used for sequential fetches and for prefetches of predicted branch targets where the branch condition has not been evaluated before the prefetch. It is also used for all non-reservation type load/store cycles.
0001	Reservation start if address type is data OR Instruction fetch marked as indirect change-of-flow if address type is instruction	If the address type is data (AT1 = 0), then this is a data access to the external bus. Both the address and the data phase are seen on the external bus. This cycle requires an $\overline{\text{AACK}}$ and a $\overline{\text{TA}}$ signal. When this cycle starts, external snooping logic should latch the address to track the reservation. If the address type is instruction (AT1 = 1), then this is an instruction fetch cycle marked as an indirect change-of-flow cycle. Both the address and the data phase are seen on the external bus. This cycle requires an $\overline{\text{AACK}}$ and a $\overline{\text{TA}}$ signal. This cycle type is used when an external address is the destination of a branch instruction or the destination of an exception or VSYNC cycle.
0010	Emulation memory select (not supported in MPC509)	This is a special external bus cycle to emulation memory replacing internal I-mem or L-mem (and not resulting in a cache hit). The MPC509 does not support this cycle type.

Table 5-14 Cycle Type Encodings (Continued)

CT[0:3]	Cycle Type	Description
0011	PRU select (not supported in MPC509)	This is a normal external bus cycle access to a port replacement chip used for emulation support. Both the address and the data phase are seen on the external bus. This cycle requires an $\overline{\text{AACK}}$ and a $\overline{\text{TA}}$ signal. It indicates that an access was made which would have gone to an internal port control register if the chip were not operating in PRU mode.
0100	I-mem (not supported in MPC509)	These are internal visibility cycles. This cycle is self-terminating and does not require $\overline{\text{AACK}}$ and $\overline{\text{TA}}$ signals. These encodings indicate that an access or aborted fetch (resulting from either a cache hit or a speculative load that is subsequently discarded) was made to an address on the internal I-bus or L-bus. An instruction access (AT1 = 1) with an address which is an indirect branch target is indicated as a write on the $\overline{\text{WR}}$ signal. The I-Mem cycle type is not supported in the MPC509.
0101	L-mem	
0110	E-Mem (external memory) cache hit, not using a chip select	This is an internal visibility cycle. It always has an address phase and includes a data phase for data accesses. This cycle is self-terminating and does not require $\overline{\text{AACK}}$ and $\overline{\text{TA}}$ signals. It indicates that an access was made to an address on the external bus and that a cache hit or aborted fetch occurred. An instruction access with an address that is an indirect branch target is indicated as a write on the $\overline{\text{WR}}$ signal.
0111	Internal register	This is an internal visibility cycle. It always has an address phase and a data phase. This cycle is self-terminating and does not require $\overline{\text{AACK}}$ and $\overline{\text{TA}}$ signals. It indicates that an access was made to a control register or internal IMB2 address. These accesses are always cache-inhibited.
1000	E-Mem cache hit to $\overline{\text{CSBOOT}}$ region	These are internal visibility cycles. They always have an address phase and include a data phase for data accesses. These cycles are self-terminating and do not require $\overline{\text{AACK}}$ and $\overline{\text{TA}}$ signals. These encodings indicate that an access was made to an address on the external bus and that a cache hit or aborted fetch occurred. An instruction access with an address that is an indirect branch target is indicated as a write on the $\overline{\text{WR}}$ signal. The region indicated is the main chip-select region, not the sub-region.
1001	E-Mem cache hit to $\overline{\text{CS1}}$ region	
1010	E-Mem cache hit to $\overline{\text{CS2}}$ region	
1011	E-Mem cache hit to $\overline{\text{CS3}}$ region	
1100	E-Mem cache hit to $\overline{\text{CS4}}$ region	
1101	E-Mem cache hit to $\overline{\text{CS5}}$ region	
1110	Reserved	—
1111	Reserved	—

5.4.13 Show Cycles

Internal bus cycles that are echoed on the external bus are referred to as show cycles. By providing access to bus cycles that are not visible externally during normal operation, show cycles allow a development support system to trace the flow of a program.

The LSHOW field in the SIUMCR can be programmed to cause the EBI to echo certain or all internal L-bus cycles on the external bus. Likewise, the ISCTL field in the ICTRL register (instruction bus control register, SPR 158) in the RCPU can be programmed to cause the EBI to echo certain or all internal I-bus cycles on the external bus.

The I-bus show cycles are always address-only cycles. They do not wait for the internal transaction to complete. L-bus show cycles have both address and data and appear on the external bus after the internal cycle is completed.

Aborted L-bus cycles do not result in a show cycle. (The load/store unit of the processor may abort the cycle when the previous cycle terminates with a transfer error, or when an exception occurs during the current cycle.)

Aborted I-bus cycles do result in a show cycle. (The processor may abort an I-bus cycle when it encounters a branch; it aborts the fetch just starting on a wrong path. In addition, the processor aborts the cycle on a cache hit.)

Note that I-bus show cycles are not burst.

A show cycle involves transfer start ($\overline{TS}$), address (ADDR), cycle type (CT), address type (AT), burst ($\overline{BURST}$) and read/write ($\overline{WR}$) pins. The data phase of an L-bus show cycle looks like a write cycle going out on the external bus. The address and data phases of a show cycle last one clock cycle each. No termination is needed for either phase, as all show cycles are automatically terminated inside the SIU. For the L-bus show cycles (I-bus show cycles are address only), the data phase always follows the address phase by one clock cycle. The L-bus show cycle does not start until the internal cycle completes. This allows all show cycles to complete in two clock cycles.

Show cycles require several holding registers in the SIU to hold address and data of an L-bus cycle and address of an I-bus cycle until the E-bus is available and the show cycle is run. When these holding registers are full, the internal bus (or buses) are held up by the SIU while it waits for the show cycle to complete.

During cross-bus accesses, the show cycle is associated with the bus initiating the transaction. For example, if I-bus show cycles are enabled and L-bus show cycles are disabled, then an instruction fetch from L-RAM will show up as an address-only I-bus show cycle, and an L-bus access to I-memory would not have a show cycle.

Refer to SECTION 8 DEVELOPMENT SUPPORT for more information on show cycles.

5.4.14 Storage Reservation Support

The PowerPC **lwarx** (load word and reserve indexed) and **stwcx.** (store word conditional indexed) instructions in combination permit the atomic update of a storage location. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details on these instructions.

The storage reservation protocol supports a multi-level bus structure like the one shown in **Figure 5-10**. In this figure, the E-bus is a PowerPC bus interfaced to a non-local bus, such as a PC/AT or VME bus, through a non-local bus interface. For each local bus, storage reservation is handled by the local reservation logic.

The protocol tries to optimize reservation cancellation such that a PowerPC processor is notified of the loss of a storage reservation on a remote bus only when it has issued

a **stwcx.** instruction to that address. That is, the reservation loss indication comes as part of the **stwcx.** cycle. This method eliminates the need to have very fast storage reservation loss indication signals routed from every remote bus to every PowerPC master.

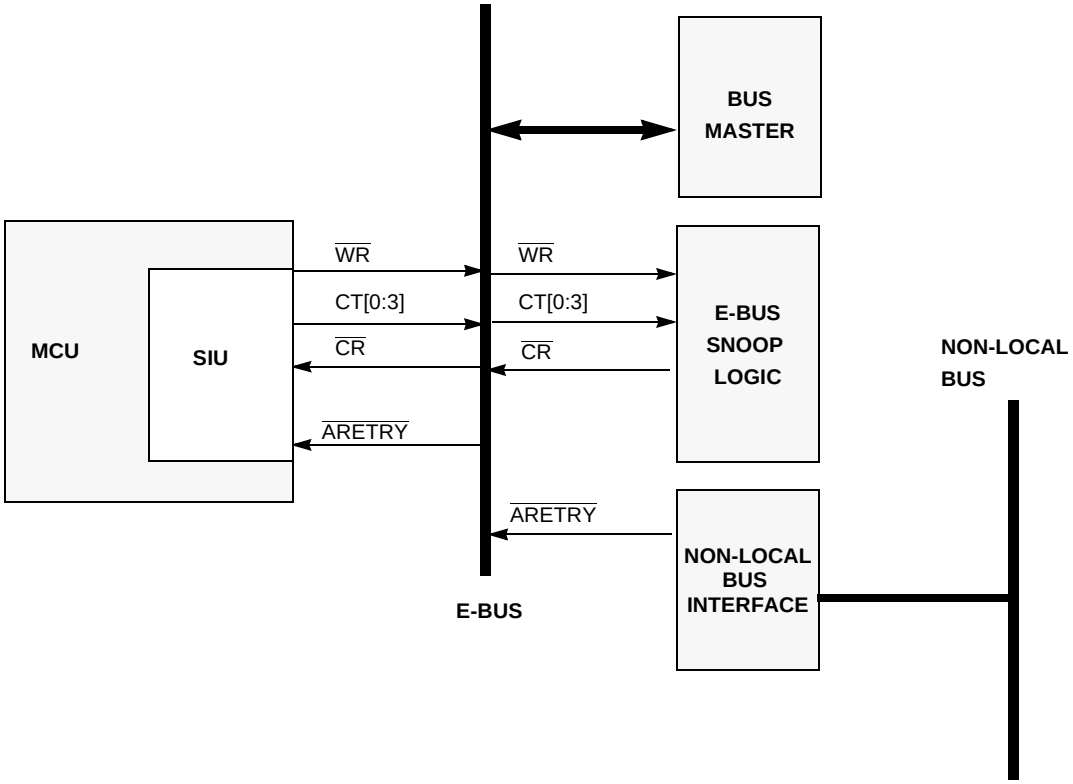


Figure 5-10 Storage Reservation Signaling

5.4.14.1 PowerPC Architecture Reservation Requirements

The PowerPC architecture requires that the reservation protocol meets the following requirements:

- Each PowerPC processor has at most one reservation.
- The **lwarx** instruction establishes a reservation.
- The **lwarx** instruction by the same processor clears the first reservation and establishes a new one.
- The **stwcx.** instruction by the same processor clears the reservation.
- A normal store by the same processor does not clear the reservation.
- A normal store by some other processor (or other mechanism, such as a DMA) to an address with an existing reservation clears the reservation.
- If the storage reservation is lost, it is guaranteed that **stwcx.** instruction will not modify storage.
- The granularity of the address compare is a multiple of the coherent block size (which should be a multiple of four bytes).

5.4.14.2 E-bus Storage Reservation Implementation

The E-bus reservation protocol requires local (external) bus reservation logic, if needed, to:

- Snoop accesses to all local bus slaves.
- Hold one reservation for each local master capable of storage reservations.
- Set the reservation when that master issues a load with reservation.
- Clear the reservation when some other master issues a store to the reservation address.
- Indicate the current status of the local bus reservation such that it may be sampled prior to the address phase of the **stwcx.** bus cycle. (The reservation must be set in time to enable a store to the reservation address, and must be cleared fast enough to disable a store to the reservation address).

The EBI samples the $\overline{\text{CR}}$ pin prior to starting an external **stwcx.** cycle. If the reservation is cancelled ($\overline{\text{CR}}$ is asserted), no cycle starts. If the reservation is not cancelled, the SIU begins the bus cycle.

If $\overline{\text{ARETRY}}$ is asserted, the SIU must re-sample the $\overline{\text{CR}}$ and $\overline{\text{BG}}$ pins prior to performing the external retry.

If a reservation exists on a non-local bus, and the SIU begins a **stwcx.** cycle to that address on the local bus while the non-local bus reservation is cleared, the $\overline{\text{ARETRY}}$ signal should be asserted to the SIU, and the reservation signal should be cleared before $\overline{\text{BG}}$ is asserted to the SIU. This means that $\overline{\text{AACK}}$ should not be returned until successful coherent completion of the **stwcx.** is ensured. The non-local bus interface must not perform the non-local write (or abort it if the bus supports aborted cycles) if it asserts $\overline{\text{ARETRY}}$.

NOTE

Single-master systems do not require an external reservation tracking logic. In these systems, the $\overline{\text{CR}}$ pin should be tied by resistor to the reservation valid (high) state. Alternatively, the reservation pin may be configured as a port. If the reservation pin is configured as a port, the SIU will always consider the reservation to be valid.

5.4.14.3 Reservation Storage Signals

Reservation storage signals used by the EBI are summarized in **Table 5-15**.

Table 5-15 EBI Storage Reservation Interface Signals

Name	Direction	Description
$\overline{CR}$	Snoop logic ⇒ SIU	Cancel reservation. Each PowerPC CPU has its own $\overline{CR}$ signal. This signal shows the status of any outstanding reservation on the external bus. When asserted, $\overline{CR}$ indicates that there is no outstanding reservation. This is a level signal.
$\overline{ARETRY}$	Non-local bus interface ⇒ SIU	Address retry. When asserted, indicates that the master needs to retry its address phase. In case of an **stwcx.** cycle to a non-local bus on which the storage reservation has been lost, this signal is used by the non-local bus interface to back off the cycle.

5.5 Chip Selects

Typical microcontrollers require additional hardware to provide external chip-select signals. In the MPC500 family, the chip-select logic controls the slaves of typical uniprocessor systems. This allows the user to implement simple systems without the need to design any external glue logic.

Figure 5-11 is an example of a typical uniprocessor system. This kind of system usually consists of a CPU, some memories, and some peripherals. In single-master systems the CPU is the only device that can be a bus master on the E-bus; memories and peripherals are slaves.

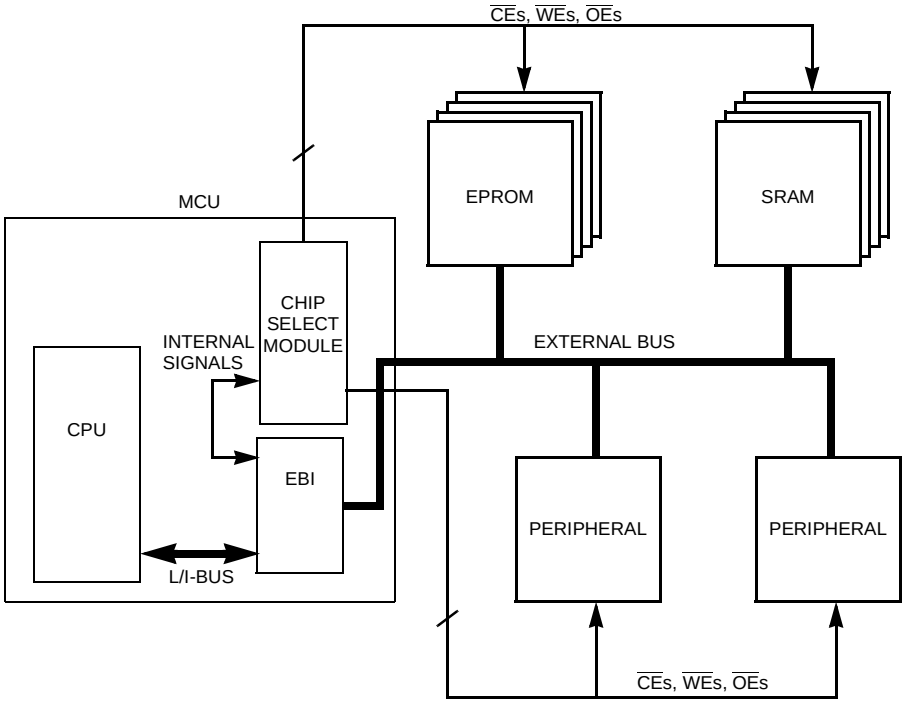


Figure 5-11 Simplified Uniprocessor System with Chip-Select Logic

The chip-select module provides the necessary control signals, such as the chip enable ($\overline{CE}$), write enable ($\overline{WE}$), and output enable ($\overline{OE}$), for the external memory and peripheral devices. In addition, the chip-select module provides some handshakes for the external bus and some limited protection mechanisms for the system.

5.5.1 Chip-Select Features

- No external glue logic required for typical systems if the chip-select module is used.
- Modular architecture for ease of expansion.
- Twelve chip-select pins plus one $\overline{CSBOOT}$ pin.
- Pins can be programmed as $\overline{CE}$s (six maximum), $\overline{OE}$s, or $\overline{WE}$s.
- Capable of supporting pipelineable, burstable devices.
- Returns bus handshake signals for the selected address regions.
- Provides up to seven programmable wait states for slave devices.
- Controls the clocking of data to the slaves during write cycles.
- Keeps slave sequentially consistent (data in the same order as addresses).
- Programmability for:
  - — Latching and non-latching device types.
  - — Burstable and non-burstable device types.
- Programmable address range and block size.
- Programmable burst features:
  - — Interruptible burst on any burstable device.
  - — Pipelineable with other devices during burst cycle.
  - — Supports two different burst protocols.
- Supports pipelineable accesses
  - — Up to two concurrent accesses can be outstanding to two different regions (one access to each region).
  - — For two consecutive accesses to the same region, overlaps the address phase of the second access with the data phase of the first access.
- Allows multi-level protection within a region. The $\overline{CSBOOT}$ region can have up to two sub-levels of protection.
- Supports both 16-bit and 32-bit port sizes.

5.5.2 Chip-Select Block Diagram

Figure 5-12 shows the functional block diagram of the chip-select module.

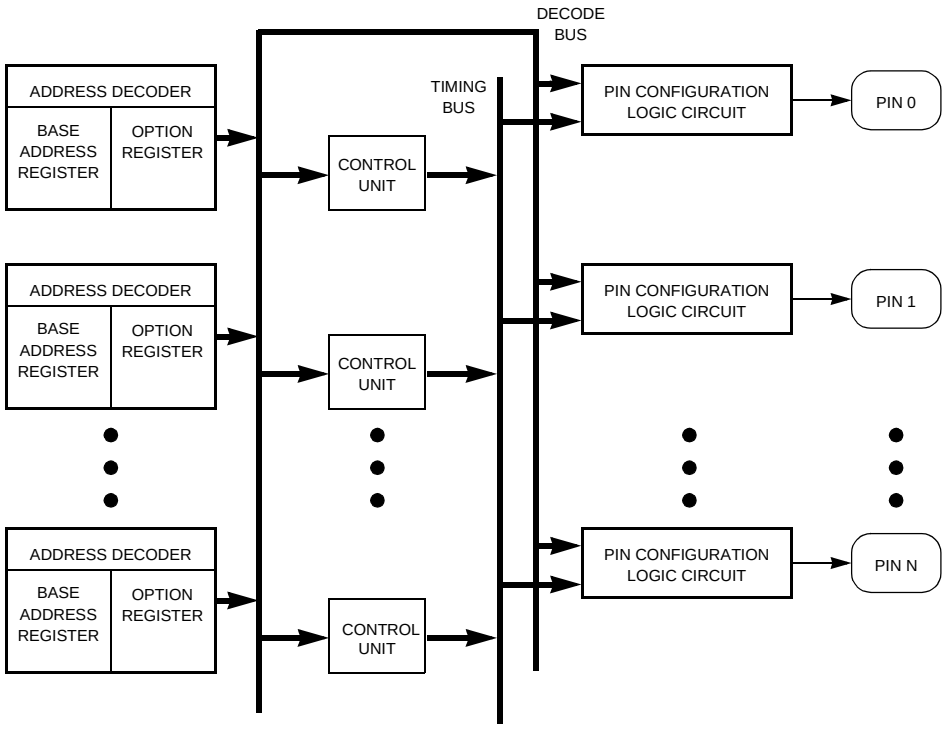


Figure 5-12 Chip-Select Functional Block Diagram

5.5.3 Chip-Select Pins

The pin configuration (PCON) field in each chip-select option register configures the associated pin to function as a chip enable ($\overline{CE}$), write enable ($\overline{WE}$), output enable ($\overline{OE}$), or alternate-function pin. For pins configured for their alternate function, the port A pin assignment register configures the pin as either an address bus signal ($\overline{ADDR[0:11]}$) or a port A or B output signal (PA[0:7] and PB[0:3]). Notice that the $\overline{CSBOOT}$ pin has no alternate function.

Table 5-16 describes the chip-select pins.

Table 5-16 Chip-Select Pin Functions

Chip-Select Function	Alternate Function	Pin Function in Chip-Select Mode
$\overline{\text{CSBOOT}}$	—	Can be the $\overline{\text{CE}}$ of the system boot memory (power-on default). In systems with no external boot device, this pin can be configured as $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS0}}$/ $\overline{\text{CSBTOE}}$	ADDR0/PA0	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs. When configured as a chip select, this pin is assigned to be the $\overline{\text{OE}}$ of the $\overline{\text{CSBOOT}}$ pin following reset.
$\overline{\text{CS1}}$	ADDR1/PA1	Can be $\overline{\text{CE}}$, $\overline{\text{WE}}$, or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS2}}$	ADDR2/PA2	Can be $\overline{\text{CE}}$, $\overline{\text{WE}}$, or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS3}}$	ADDR3/PA3	Can be $\overline{\text{CE}}$, $\overline{\text{WE}}$, or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS4}}$	ADDR4/PA4	Can be $\overline{\text{CE}}$, $\overline{\text{WE}}$, or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS5}}$	ADDR5/PA5	Can be $\overline{\text{CE}}$, $\overline{\text{WE}}$, or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS6}}$	ADDR6/PA6	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS7}}$	ADDR7/PA7	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS8}}$	ADDR8/PB0	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS9}}$	ADDR9/PB1	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS10}}$	ADDR10/PB2	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.
$\overline{\text{CS11}}$	ADDR11/PB3	Can be $\overline{\text{WE}}$ or $\overline{\text{OE}}$ of EPROMs or SRAMs.

NOTE

During the first two clock cycles of power-on reset, the state of the pins listed in **Table 5-16** is unknown.

When a chip select is configured as a chip enable of a memory or I/O device, the MCU asserts the chip select when it drives the address onto the external bus. For non-pipelineable devices, the $\overline{\text{CE}}$ is asserted until the access is completed. For pipelineable devices, when $\overline{\text{CE}}$ is asserted the device should clock in the address at the rising edge of the clock. (Note that devices that the chip-select unit regards as pipelineable are always synchronous.)

The $\overline{\text{WE}}$ signal is used during write accesses. When a chip select is configured as a write enable signal of a memory or I/O device, the MCU asserts the chip select as it drives data onto the external bus to signal the external device to strobe in the data. For synchronous devices, if $\overline{\text{WE}}$ is asserted the device should clock in the data at the rising edge of the clock.

The $\overline{\text{OE}}$ signal is used during read accesses. When the MCU asserts a chip-select signal that is configured as an output enable of a memory or I/O device, the device can drive its data onto the E-bus.

5.5.4 Chip-Select Registers and Address Map

Chip-select registers are 32 bits wide. Reads of unimplemented bits in these registers return zero, and writes have no effect.

One base address register and one option register are associated with each chip-select pin that can function as a chip enable. The CSBOOT pin has a dedicated sub-block for multi-level protection. It has two base address registers and two option registers. One option register is associated with each pin that can function as a write enable or output enable but not as a chip enable.

Table 5-17 is an address map of the chip-select module. As the entries in the Access column indicate, all chip-select registers are accessible at the supervisor privilege level only.

When set, the LOK bit in the SIU module configuration register (SIUMCR) locks all chip-select registers to prevent software from changing the chip-select configuration inadvertently. Before changing the chip-select configuration, the user needs to ensure that this bit is cleared.

Note that if the processor is modifying the chip-select registers of a region and it needs the instructions from that region (a region that it is reconfiguring), software needs to ensure that the code is accessible elsewhere. For example, if the processor is configuring the CSBOOT registers and simultaneously executing instructions out of the boot region, software can re-locate the necessary code to the instruction cache, internal SRAM, or to another external region such as external SRAM, before modifying the chip-select control registers.

Table 5-17 Chip-Select Module Address Map

Access	Address	Register
—	0x8007 FD00 – 0x8007 FD90	Reserved
S	0x8007 FD94	$\overline{\text{CS11}}$ Option Register (CSOR11)
S	0x8007 FD98	Reserved
S	0x8007 FD9C	$\overline{\text{CS10}}$ Option Register (CSOR10)
S	0x8007 FDA0	Reserved
S	0x8007 FDA4	$\overline{\text{CS9}}$ Option Register (CSOR9)
S	0x8007 FDA8	Reserved
S	0x8007 FDAC	$\overline{\text{CS8}}$ Option Register (CSOR8)
S	0x8007 FDB0	Reserved
S	0x8007 FDB4	$\overline{\text{CS7}}$ Option Register (CSOR7)
S	0x8007 FDB8	Reserved
S	0x8007 FDBC	$\overline{\text{CS6}}$ Option Register (CSOR6)
S	0x8007 FDC0	$\overline{\text{CS5}}$ Base Address Register (CSBAR5)
S	0x8007 FDC4	$\overline{\text{CS5}}$ Option Register (CSOR5)
S	0x8007 FDC8	$\overline{\text{CS4}}$ Base Address Register (CSBAR4)
S	0x8007 FDCC	$\overline{\text{CS4}}$ Option Register (CSOR4)
S	0x8007 FDD0	$\overline{\text{CS3}}$ Base Address Register (CSBAR3)
S	0x8007 FDD4	$\overline{\text{CS3}}$ Option Register (CSOR3)
S	0x8007 FDD8	$\overline{\text{CS2}}$ Base Address Register (CSBAR2)
S	0x8007 FDDC	$\overline{\text{CS2}}$ Option Register (CSOR2)
S	0x8007 FDE0	$\overline{\text{CS1}}$ Base Address Register (CSBAR1)
S	0x8007 FDE4	$\overline{\text{CS1}}$ Option Register (CSOR1)
S	0x8007 FDE8	Reserved
S	0x8007 FDEC	$\overline{\text{CS0}}$ Option Register (CSOR0)
S	0x8007 FDF0	$\overline{\text{CSBOOT}}$ Sub-Block Base Address Register (CSBTSBBAR)
S	0x8007 FDF4	$\overline{\text{CSBOOT}}$ Sub-Block Option Register (CSBTSBOR)
S	0x8007 FDF8	$\overline{\text{CSBOOT}}$ Base Address Register (CSBTBAR)
S	0x8007 FDFC	$\overline{\text{CSBOOT}}$ Option Register (CSBTOR)

5.5.4.1 Chip-Select Base Address Registers

Base address registers contain the base address of the range of memory to which the chip select circuit responds. All base address registers contain the same fields but have different reset values.

CSBTBAR — $\overline{\text{CSBOOT}}$ Base Address Register **0x8007 FDF8**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
BA																				RESERVED											
RESET:																															
IP	IP	IP	IP	IP	IP	IP	IP	IP	IP	IP	IP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The reset value of the BA field in the CSBTBAR equals 0x00000 if the exception prefix (IP) bit in the MSR is zero (default), and 0xFFF00 if IP equals one.

CSBTSBBAR — $\overline{\text{CSBOOT}}$ Sub-Block Base Address Register **0x8007 FDF0**
CSBAR1 — $\overline{\text{CS1}}$ Base Address Register **0x8007 FDE0**
CSBAR2 — $\overline{\text{CS2}}$ Base Address Register **0x8007 FDD8**
CSBAR3 — $\overline{\text{CS3}}$ Base Address Register **0x8007 FDD0**
CSBAR4 — $\overline{\text{CS4}}$ Base Address Register **0x8007 FDC8**
CSBAR5 — $\overline{\text{CS5}}$ Base Address Register **0x8007 FDC0**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
BA																				RESERVED											
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5-18 Chip-Select Base Address Registers Bit Settings

Bit(s)	Name	Description
0:19	BA	Base address. Bits 0 through 19 of the base address of the block to which the chip select responds. Register bit 0 corresponds to address bit 0; register bit 19 corresponds to address bit 19.
20:31	—	Reserved.

5.5.4.2 Chip-Select Option Registers

CSBTOR, the option register for $\overline{\text{CSBOOT}}$, has the same field definitions as the option registers for $\overline{\text{CS}}$[1:5] but has different reset values. The $\overline{\text{CS0}}$ and $\overline{\text{CS}}$[6:10] option registers contain a subset of the fields in the CSBTOR. The $\overline{\text{CSBOOT}}$ sub-block option register contains a different subset of the fields in the CSBTOR.

The reset values of several bits in the chip-select option registers depend on the data bus configuration word (the state of the internal data bus) at reset. The TADLY field in the $\overline{\text{CSBOOT}}$ option register is read from the internal DATA[6:8] bits, and the PS field is determined from DATA4. In addition, the reset value of the PCON field in the option registers for $\overline{\text{CS}}$[0:11] depends on the value of internal DATA0 at reset. If DATA0 = 1, the $\overline{\text{CS}}$[0:11]/ADDR[0:11] pins are configured as chip selects, and the PCON field at reset is 0b10 (output enable) for $\overline{\text{CS0}}$ and 0b00 (chip enable) for $\overline{\text{CS}}$[0:11]. If internal DATA0 = 0 at reset, the pins are configured as address pins, and the PCON field values for all option registers are 0b11 (non-chip-select function). Refer to **5.8.3 Configuration During Reset** for more information on the data bus configuration word.

CSBTOR — $\overline{\text{CSBOOT}}$ Option Register — 0x8007 FDFC

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BSIZE				SBLK	SUPV	DSP	WP	CI	RESERVED				ACK-EN	TADLY	
RESET:															
1	0	0	1	0	1	0	1	0	0	0	0	0	1	*	*

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
TAD-LY	PS		PCON		BYTE		REGION			RESERVED		ITYPE			
RESET:															
*	*	*	0	0	0	0	0	0	0	0	0	*	*	*	*

*From data bus reset configuration word

CSBTSBOR — $\overline{\text{CSBOOT}}$ Sub-Block Option Register — 0x8007 FDF4

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BSIZE				SBLK	SUPV	DSP	WP	CI	RESERVED						
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CSOR0 — $\overline{\text{CS0}}$ Option Register — 0x8007 FDEC

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED			PCON		BYTE		REGION			RESERVED					
RESET:															
0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0

*0b10 if pins are configured as chip selects at reset, otherwise 0b11

CSOR1 — $\overline{CS1}$ Option Register **0x8007 FDE4**
CSOR2 — $\overline{CS2}$ Option Register **0x8007 FDDC**
CSOR3 — $\overline{CS3}$ Option Register **0x8007 FDD4**
CSOR4 — $\overline{CS4}$ Option Register **0x8007 FDCC**
CSOR5 — $\overline{CS5}$ Option Register **0x8007 FDC4**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BSIZE				SBLK	SUPV	DSP	WP	CI	RESERVED				ACK-EN	TADLY	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
TAD-LY	PS		PCON		BYTE		REGION			RESERVED		ITYPE			
RESET:															
0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0

*0b00 if pins are configured as chip selects at reset, otherwise 0b11

CSOR6 — $\overline{CS6}$ Option Register **0x8007 FDBC**
CSOR7 — $\overline{CS7}$ Option Register **0x8007 FDB4**
CSOR8 — $\overline{CS8}$ Option Register **0x8007 FDAC**
CSOR9 — $\overline{CS9}$ Option Register **0x8007 FDA4**
CSOR10 — $\overline{CS10}$ Option Register **0x8007 FD9C**
CSOR11 — $\overline{CS11}$ Option Register **0x8007 FD94**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED			PCON		BYTE		REGION			RESERVED					
RESET:															
0	0	0	*	*	0	0	0	0	0	0	0	0	0	0	0

*0b00 if pins are configured as chip selects at reset, otherwise 0b11

Table 5-19 describes the fields in the chip-select option registers.

Table 5-19 Chip-Select Option Register Bit Settings

Bit(s)	Name	Description
0:3	BSIZE	Block size. This field determines the size of the block associated with the base address. 0000 = Disables corresponding region 0001 = 4 Kbytes 0010 = 8 Kbytes 0011 = 16 Kbytes 0100 = 32 Kbytes 0101 = 64 Kbytes 0110 = 128 Kbytes 0111 = 256 Kbytes 1000 = 512 Kbytes 1001 = 1 Mbyte 1010 = 2 Mbytes 1011 = 4 Mbytes 1100 = 8 Mbytes 1101 = 16 Mbytes 1110 = 32 Mbytes 1111 = 64 Mbytes Refer to **5.5.5 Chip-Select Regions** for more information.
4	SBLK	Sub-block 0 = Address space is a main block 1 = Address space specified by the BA and BSIZE fields of the corresponding base address and option registers, respectively, is a sub-block within a larger main block. Pairing of main blocks and sub-blocks is as follows: $\overline{CSBOOT}$ and $\overline{CS1}$ $\overline{CS2}$ and $\overline{CS3}$ $\overline{CS4}$ and $\overline{CS5}$ Refer to **5.5.6 Multi-Level Protection** for more information.
5	SUPV	Supervisor mode 0 = Access is permitted in supervisor or user mode 1 = Access is permitted in supervisor mode only Refer to **5.5.7.1 Supervisor Space Protection** for more information.
6	DSP	Data space only 0 = Address block may contain both instructions and data. 1 = Address block contains data only. Refer to **5.5.7.2 Data Space Protection** for more information.
7	WP	Write protect 0 = Block is available for both read and write operations 1 = Block is read only Refer to **5.5.7.3 Write Protection** for more information.
8	CI	Cache inhibit 0 = Information in this block can be cached. 1 = Information in this block should not be cached. Refer to **5.5.8 Cache Inhibit Control** for more information.
9:12	—	Reserved
13	ACKEN	Acknowledge enable. 0 = Chip-select logic will not return $\overline{TA}$ and $\overline{AACK}$ signals 1 = Chip-select logic will return $\overline{TA}$ and $\overline{AACK}$ signals Refer to **5.5.9 Handshaking Control** for more information.

Table 5-19 Chip-Select Option Register Bit Settings (Continued)

Bit(s)	Name	Description
14:16	TADLY	$\overline{TA}$ delay. Indicates the latency of the device for the first $\overline{TA}$ returned. Up to seven wait states are allowed. 000 = 0 wait states 001 = 1 wait state 010 = 2 wait states 011 = 3 wait states 100 = 4 wait states 101 = 5 wait states 110 = 6 wait states 111 = 7 wait states Refer to **5.5.10 Wait State Control** for more information.
17:18	PS	Port size 00 = Reserved 01 = 16-bit port 10 = 32-bit port 11 = Reserved Refer to **5.5.11 Port Size** for more information.
19:20	PCON	Pin configuration. Note that only pins $\overline{CSBOOT}$ and $\overline{CS}$[1:5] can be $\overline{CE}$ pins. 00 = Chip enable ($\overline{CE}$) 01 = Write enable ($\overline{WE}$) 10 = Output enable ($\overline{OE}$) 11 = Alternate function (address bus or discrete output) Refer to **5.5.12.1 Pin Configuration** for more information.
21:22	BYTE	Byte enable. This field applies to pins configured as $\overline{WE}$s only. Specifies for which of the four bytes in a word the $\overline{WE}$ is asserted. If the region can always be written in 32-bit quantity, this field can be programmed to any value. 00 = Byte enable 0 01 = Byte enable 1 10 = Byte enable 2 11 = Byte enable 3 Refer to **5.5.12.2 Byte Enable Control** for more information.
23:25	REGION	Memory region (only applicable when pin is configured to be a $\overline{WE}$ or $\overline{OE}$ pin). These bits indicate the memory region with which the pin is associated. 000 = $\overline{CSBOOT}$ 001 = $\overline{CS1}$ 010 = $\overline{CS2}$ 011 = $\overline{CS3}$ 100 = $\overline{CS4}$ 101 = $\overline{CS5}$ 110 = Reserved 111 = Reserved Refer to **5.5.5 Chip-Select Regions** for more information.
26:27	—	Reserved
28:31	ITYPE	Interface type. Indicates the type of memory or peripheral device being controlled. Refer to **5.5.13 Interface Types** for details.

5.5.5 Chip-Select Regions

The SIU supports an address space of four gigabytes (2^{32} bytes). This space can be divided into regions. Each region can be occupied by one or more chips, depending on the output width of each chip.

Each chip-select pin that is programmed as a chip enable defines a separate region. Only the CSBOOT and CS[1:5] pins can serve as chip enables. All chips within a region have a common chip enable signal.

Each chip select that can be programmed as a chip enable has an associated base address register. In addition, the CSBOOT sub-block circuit has a base address register. The base address register specifies the base address of the memory or peripheral controlled by the chip select.

The base address and block size together determine the range of addresses controlled by a chip select. Block size is the extent of the address block above the base address. Block size is specified in the BSIZE field of the chip-select option register.

The BA (base address) field in the chip-select base address register contains the high-order bits (bits 0 through 19) of the address block to which the associated chip select responds. Register bit 0 corresponds to ADDR0; register bit 19 corresponds to ADDR19. The BSIZE field determines how many of these bits are actually compared. For the smallest block size encoding (four Kbytes), bits 0 through 19 are compared with ADDR[0:19]. For larger block sizes, not all of these bits are compared. **Table 5-20** shows the block size and address lines compared for each BSIZE encoding.

Table 5-20 Block Size Encoding

BSIZE Field (Binary)	Block Size (Bytes)	Address Lines Compared
0000	Invalid	Chip select is not asserted until BSIZE field is assigned a non-zero value.
0001	4 K	ADDR[0:19]
0010	8 K	ADDR[0:18]
0011	16 K	ADDR[0:17]
0100	32 K	ADDR[0:16]
0101	64 K	ADDR[0:15]
0110	128 K	ADDR[0:14]
0111	256 K	ADDR[0:13]
1000	512 K	ADDR[0:12]
1001	1 M	ADDR[0:11]
1010	2 M	ADDR[0:10]
1011	4 M	ADDR[0:9]
1100	8 M	ADDR[0:8]
1101	16 M	ADDR[0:7]
1110	32 M	ADDR[0:6]
1111	64 M	ADDR[0:5]

Since the address decode logic of the chip select uses only the most significant address bits to determine an address match within its block size, the value of the base address must be a multiple of the corresponding block size.

Although the base address registers can be programmed to be any address within the address map, the user must avoid programming these registers to values that overlap the addresses of internal modules. At power-on time, the address of the boot device may match that of an internal module, because a system can have on-chip EPROM for instructions. If this occurs, the internal access overrides the external access. That is, the internal access provides the boot instructions, and the chip-select unit does not run an external cycle.

The reset value of the BA field in the $\overline{\text{CSBOOT}}$ base address register depends on the value of the exception prefix (IP) bit in the machine state register. Refer to the *RCPU Reference Manual* (RCPURM/AD) for a description of the machine state register.

5.5.6 Multi-Level Protection

The chip-select unit allows protection for an address space within another address space. **Figure 5-13** illustrates this concept.

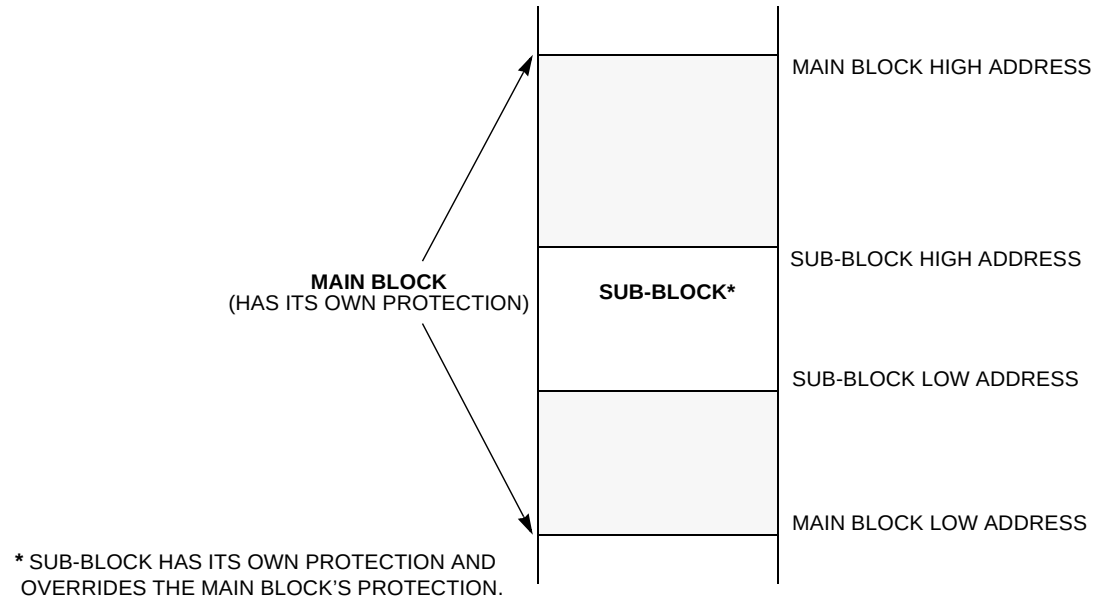


Figure 5-13 Multi-Level Protection

Figure 5-13 shows a sub-block contained within a main block. The main block and the sub-block can have different protection mechanisms programmed. For example, the user can have a separate data space and instruction space within a single chip-select region.

The block size of the sub-block should be less than the block size of the main block. The protection of the smaller block overrides the protection of the main block.

5.5.6.1 Main Block and Sub-Block Pairings

Multi-level protection is accomplished using a paired set of chip-select decoding circuits. The decoding pairs are specified in **Table 5-21**.

Table 5-21 Main Block and Sub-Block Pairings

Main Block	Sub-Block
$\overline{\text{CSBOOT}}$	$\overline{\text{CS1}}$
$\overline{\text{CS2}}$	$\overline{\text{CS3}}$
$\overline{\text{CS4}}$	$\overline{\text{CS5}}$

If the address of an access falls within a sub-block, the protection of the sub-block overrides that of the main block. (The sub-block decoding logic overrides the decoding logic of the main block.) If all match conditions are met, the chip-select pin of the main block is asserted.

Notice that only $\overline{\text{CSBOOT}}$ and $\overline{\text{CS}}$[1:5] are involved in the sub-block protection scheme. These are the chip selects with address decoding logic (i.e., they can act as chip enables).

5.5.6.2 Programming the Sub-Block Option Register

When the SBLK bit in CSOR1, CSOR3, or CSOR5 is set, the corresponding address block (defined by the BA and BSIZE fields) is designated a sub-block. **Table 5-21** indicates the main block to which the sub-block is assigned.

When the SBLK bit in one of these registers is set, the following fields in the sub-block option register must be programmed to the same values as in the option register for the corresponding main block: ITYPE, ACKEN, TADLY, and PS. If there is a discrepancy in the encoding of any of these bits in the two option registers, the chip-select unit uses the bits that are set in either register (i.e., it performs a logical OR on the associated bits in the two registers).

When the SBLK bit in CSOR1, CSOR3, or CSOR5 is set, the corresponding chip-select pin cannot act as a $\overline{\text{CE}}$ pin, since its decoder is used for multi-level protection. The pin, however, can still be configured (by programming the PCON field) to function as an $\overline{\text{OE}}$, $\overline{\text{WE}}$, or non-chip-select pin. If the pin is configured as a $\overline{\text{WE}}$ or $\overline{\text{OE}}$, it can be assigned to any region (not just the region associated with the sub-block).

The $\overline{\text{CSBOOT}}$, $\overline{\text{CS2}}$, and $\overline{\text{CS4}}$ regions cannot be sub-blocks. They can only be the main blocks. Setting the SBLOCK bit in any of these registers has no effect.

5.5.6.3 Multi-Level Protection for $\overline{\text{CSBOOT}}$

The $\overline{\text{CSBOOT}}$ region has a dedicated sub-block decoder in addition to its paired sub-block decoder ($\overline{\text{CS1}}$). If both sub-block decoders are used, the $\overline{\text{CS1}}$ decoder has higher priority than the dedicated sub-block decoder. That is, if an address is contained in both sub-blocks, the protections specified in the $\overline{\text{CS1}}$ option register are used. If an address is contained in the dedicated sub-block (and the $\overline{\text{CSBOOT}}$ main block) but not the $\overline{\text{CS1}}$ sub-block, the protections specified in the $\overline{\text{CSBOOT}}$ sub-block option register are used.

The SBLK bit of the dedicated sub-block option register is cleared at power-on. The bit can be modified after reset if needed. The boot region would need to contain enough

instructions to reconfigure the chip-select registers to provide multi-level protection shortly after power-on.

5.5.7 Access Protection

The SUPV, DSP, and WP bits in the option registers for CSBOOT, the CSBOOT sub-block, and CS[1:5] control access to the address block assigned to the chip select. These bits are present in the option registers for chip selects with address decoding logic only; they are not present in the option registers for CS0 or CS[6:11]. In addition, the bits take effect only if the chip select is programmed either as a CE or as a sub-block.

If the chip-select unit detects a protection violation, it asserts the internal TEA signal and does not assert the external chip enable signal. Assertion of TEA causes the processor to enter the checkstop state, enter debug mode, or process a machine check exception. Refer to the *RCPU Reference Manual* (RCPURM/AD) for details.

5.5.7.1 Supervisor Space Protection

The SUPV bit in the option registers for CSBOOT, the CSBOOT sub-block, and CS[1:5] controls user-level access to the associated region. If the bit is set, access is permitted at the supervisor privilege level only. If the bit is cleared, both supervisor- and user-level accesses are permitted.

When an access is made to the region assigned to the chip select, the chip-select logic compares the SUPV bit with the internal AT0 signal, which indicates whether the access is at the user (AT0 = 0) or supervisor (AT0 = 1) privilege level. If the chip-select logic detects a protection violation (SUPV = 1 and AT0 = 0), it asserts the internal TEA signal and does not assert the external chip enable signal.

This protection applies to data address space only. The chip-select logic does not check for supervisor access protection on instruction accesses.

5.5.7.2 Data Space Protection

The DSP bit in the option registers for CSBOOT, the CSBOOT sub-block, and CS[1:5] controls whether instruction access is allowed to the address block associated with the chip select. If DSP is set, the address block is designated as data space; no instruction access is allowed. This feature can be used to prevent the system from inadvertently executing instructions out of data space.

When an access is made to the region controlled by the chip select, the chip-select logic compares the DSP bit with the internal AT1 signal, which indicates whether the access is to instruction or data space. If the chip-select logic detects a protection violation (DSP = 1 and AT1 = 1), it asserts the internal TEA signal and does not assert the external chip enable signal.

5.5.7.3 Write Protection

The WP bit in the option registers for CSBOOT, the CSBOOT sub-block, and CS[1:5] controls whether the address block is write-protected. If WP is set, read accesses only

are permitted. If WP is cleared, both read and write accesses are allowed. This feature permits the user to protect certain regions, such as ROM regions, from being inadvertently written.

When an access is made to the region controlled by the chip select, the chip-select logic compares the WP bit with the internal $\overline{WR}$ signal, which indicates whether the access is a read or a write. If the chip-select logic detects a protection violation (WP = 1 and $\overline{WR}$ = 0), it asserts the internal $\overline{TEA}$ signal and does not assert the external chip enable signal.

5.5.8 Cache Inhibit Control

The CI (cache inhibit) bit in the option registers for $\overline{CSBOOT}$, the $\overline{CSBOOT}$ sub-block, and $\overline{CS}$[1:5] controls whether the information in the address block can be cached. The chip-select logic provides the status of this bit to the cache during the data phase of an access. If CI is set, the data in the region is not cached.

5.5.9 Handshaking Control

The acknowledge enable (ACKEN) bit in the option registers for $\overline{CSBOOT}$ and $\overline{CS}$[1:5] determines whether the chip-select logic returns address acknowledge ($\overline{AACK}$) and transfer acknowledge ($\overline{TA}$) signals for the region. When ACKEN is set, the chip-select logic returns these signals. (When ACKEN is set, external logic can still return these signals. If it does, it must assert them before the chip-select logic asserts the signals internally.) When ACKEN is cleared, the external device must return them.

When ACKEN is cleared, the chip-select logic still returns the $\overline{BI}$ and PS[0:1] signals. Since the chip-select logic does not return the $\overline{TA}$ signal, the TADLY field, indicating the number of wait states before $\overline{TA}$ assertion, is not used.

After power-on, the $\overline{CSBOOT}$ circuit is enabled to return $\overline{AACK}$ and $\overline{TA}$. If the external boot device returns the $\overline{TA}$ signal, however, before the chip-select logic asserts $\overline{TA}$ internally, the external $\overline{TA}$ assertion terminates the access.

5.5.10 Wait State Control

The TADLY field in the option registers for $\overline{CSBOOT}$ and $\overline{CS}$[1:5] indicates the number of wait states for the chip-select logic to insert before returning $\overline{TA}$. If this field is encoded for zero wait states, $\overline{TA}$ is asserted one clock cycle after $\overline{TS}$ is asserted. An encoding of one wait state means that $\overline{TA}$ is asserted two clock cycles after $\overline{TS}$, and so on. Up to seven wait states are allowed. The encodings are shown in **Table 5-22**.

Table 5-22 TADLY and Wait State Control

TADLY	Wait States
0b000	0
0b001	1
0b010	2
0b011	3
0b100	4
0b101	5
0b110	6
0b111	7

Note this field is used only when the chip-select logic returns the handshaking signals (ACKEN = 1).

Note that the user does not program the number of wait states prior to $\overline{\text{AACK}}$ assertion. The chip-select logic uses the following scheme to determine when to assert $\overline{\text{AACK}}$:

- If the region is an asynchronous type, $\overline{\text{AACK}}$ is asserted at the end of access to the region.
- If the region is pipelineable and the region is not busy with a pending access, $\overline{\text{AACK}}$ is asserted after the address is latched by the region (i.e., at the next rising clock edge).
- If the region is pipelineable and the region is busy with a pending access, $\overline{\text{AACK}}$ is asserted for the next access to the region at the end of the pending access to the region (i.e., when $\overline{\text{TA}}$ is asserted for that access).

5.5.11 Port Size

The PS field indicates the port size of the region. The chip-select logic always returns PS[0:1] for regions under its control. Port size encoding is shown in **Table 5-23**. The 0b00 and 0b11 encodings are reserved; if one of these encodings is used, the port size defaults to 32 bits.

Table 5-23 Port Size

PS Field	Port Size
0b00	Reserved
0b01	16 bits
0b10	32 bits
0b11	Reserved

5.5.12 Chip-Select Pin Control

The PCON, BYTE, and REGION fields of each chip-select option register control how the associated pin is used. The PCON field determines pin function ($\overline{\text{CE}}$, $\overline{\text{OE}}$, $\overline{\text{WE}}$, or alternate function). The BYTE field determines which byte enable a $\overline{\text{WE}}$ pin corresponds to. The REGION field assigns a $\overline{\text{WE}}$ or $\overline{\text{OE}}$ pin to one of six chip-select regions.

5.5.12.1 Pin Configuration

The PCON (pin configuration) field in the chip-select option register configures the associated pin to be a $\overline{CE}$, $\overline{WE}$, $\overline{OE}$, or non-chip-select function pin. The encodings are shown in **Table 5-24**.

Table 5-24 Pin Configuration Encodings

PCON	Pin Assignment
0b00	Chip enable ($\overline{CE}$)
0b01	Write enable ($\overline{WE}$)
0b10	Output enable ($\overline{OE}$)
0b11	Address pin or discrete output

Note that only the $\overline{CSBOOT}$ and $\overline{CS}$[1:5] pins can be $\overline{CE}$ pins. If the pin is a $\overline{CE}$ pin, the REGION field does not affect it, since each $\overline{CE}$ pin has its own base address register and decoding logic.

The $\overline{CS0}$ and $\overline{CS}$[6:11] pins cannot be $\overline{CE}$ pins. If one of these pins is configured as a chip enable, the pin is never asserted.

A PCON encoding of 0b11 assigns the pin to its alternate function. In this case, the value in the port A/B pin assignment register (PABPAR) determines whether the pin operates as an address pin or discrete output pin. Refer to 5.9.3 Ports A and B for more information.

5.5.12.2 Byte Enable Control

The BYTE field is applicable only for pins configured as $\overline{WE}$ pins. This field is used to determine to which of the four E-bus byte enables the pin corresponds. That is, the $\overline{WE}$ pin will be asserted only when the corresponding E-bus byte enable is asserted. The encoding is shown in **Table 5-25**. If the region can always be written in 32-bit quantity, this field can be programmed to any value.

Table 5-25 BYTE Field Encodings

BYTE	Byte Enabled
0b00	Byte enable 0
0b01	Byte enable 1
0b10	Byte enable 2
0b11	Byte enable 3

If the pin is configured as an $\overline{OE}$, this field is not used. (It is assumed the $\overline{OE}$ pin enables the outputs of all four bytes of the region onto the 32-bit E-bus.) Thus, typically a writable region would have multiple $\overline{WE}$s, one $\overline{OE}$, and one $\overline{CE}$.

5.5.12.3 Region Control

The REGION field indicates which memory region the pin is assigned to. This field is used only when the pin is configured to be a $\overline{WE}$ or $\overline{OE}$ pin. For example, a PCON

encoding of 0b10 and a REGION encoding of 0b001 configures the pin as an $\overline{OE}$ of the memory region defined by $\overline{CS1}$.

REGION field encodings are shown in **Table 5-26**.

Table 5-26 REGION Field Encodings

REGION	Memory Region Defined by
0b000	$\overline{CSBOOT}$
0b001	$\overline{CS1}$
0b010	$\overline{CS2}$
0b011	$\overline{CS3}$
0b100	$\overline{CS4}$
0b101	$\overline{CS5}$
0b110	Reserved
0b111	Reserved

5.5.13 Interface Types

The chip-select module supports a wide variety of devices. The interface type (ITYPE) field in the option registers for $\overline{CSBOOT}$ and $\overline{CS}$[1:5] identifies the characteristics of the device interface. These characteristics include whether the external device interface:

- Is synchronous or asynchronous
- Supports pipelined accesses
- Can hold off its internal data
- Has a synchronous $\overline{OE}$, an asynchronous $\overline{OE}$, or no $\overline{OE}$
- Is burstable or non-burstable
- Uses the $\overline{LAST}$ or $\overline{BDIP}$ protocol for ending a burst transmission

The following paragraphs define these concepts.

A burstable device can accept one address and drive out multiple data beats. A burstable device must be synchronous. (Note that devices with fast static column access are not considered burstable. This class of devices is considered asynchronous.)

Two accesses are overlapped if they are aligned such that the address of the second access is on the external bus at the same time as the data of the first access.

Two accesses are pipelined if they are aligned such that the address of the second access is on the external bus before the data of the first access.

A device is pipelineable if it can latch the address presented to it and does not require the address to be valid on its address pins for the duration of the access to the device. The pipelineable device should latch the address at the rising edge of the clock when its $\overline{CE}$ is asserted. Note that only synchronous devices are treated as pipelineable by the chip-select logic.

$\overline{\text{BDIP}}$ and $\overline{\text{LAST}}$ are the early termination control signals for burst cycles. A memory device with a type 1 burst interface may have a $\overline{\text{BDIP}}$ signal as one of its inputs. A memory device with a type 2 burst interface has a $\overline{\text{LAST}}$ signal as one of its inputs. Refer to 5.5.16.6 Synchronous Burst Interface for a description of these interface types.

A device may or may not have the ability to hold off its data output until the data bus is available to the device. To be able to hold off its data the device needs an $\overline{\text{OE}}$ control input, and if the device is burstable it also needs the ability to suspend its internal state machine from advancing to the next data beat until the data bus has been granted to it. An example of this is a memory device with burst address advance control such as $\overline{\text{BDIP}}$ to control the incrementing of its internal address counter.

5.5.13.1 Interface Type Descriptions

Table 5-27 lists the characteristics of each interface type. Note that if software programs the ITYPE field to one of the reserved values, the chip-select signal will never be asserted.

Table 5-27 Interface Types

ITYPE (Binary)	Interface Type
0000	Generic asynchronous region with output buffer turn-off time of less than or equal to one clock period (see **5.5.13.2 Turn-Off Times for Different Interface Types**). A device of this type cannot be pipelined. Refer to **Figure 5-17** and **Figure 5-18**.
0001	Generic asynchronous region with output buffer turn-off time of two clock periods (see **5.5.13.2 Turn-Off Times for Different Interface Types**). A device of this type cannot be pipelined. The chip-select logic inserts a dead clock between two subsequent accesses to the same region of this type in order to satisfy the high time required by the $\overline{\text{CE}}$ and $\overline{\text{WE}}$ of some memory types.
0010	Synchronous region (no burst) with asynchronous $\overline{\text{OE}}$. Refer to **Figure 5-19** and **Figure 5-20**. A device with this type of interface is pipelineable, can function as an asynchronous device, and has the ability to hold off its internal data on a read access until $\overline{\text{OE}}$ is asserted. Note that with this interface type, if the MCU receives $\overline{\text{TA}}$ before asserting $\overline{\text{OE}}$, $\overline{\text{OE}}$ may still be asserted and may remain asserted.
0011	Synchronous region (no burst) with synchronous $\overline{\text{OE}}$. Refer to **Figure 5-21**. A device with this type of interface is pipelineable, can function as an asynchronous device, and has the ability to hold off its internal data on a read access until $\overline{\text{OE}}$ is asserted. The chip-select logic asserts $\overline{\text{OE}}$ for one clock cycle on accesses to devices with this interface type. A device with synchronous $\overline{\text{OE}}$ must be programmed for one or more wait states. If the region is programmed for zero wait states with synchronous $\overline{\text{OE}}$, the chip-select logic still generates the $\overline{\text{OE}}$ as if the region were programmed for one wait state.
0100	Reserved.

Table 5-27 Interface Types (Continued)

ITYPE (Binary)	Interface Type
0101	Region with fixed burst access capability (burst type 1) and asynchronous $\overline{OE}$. Refer to **Figure 5-23** and **Figure 5-24**. A device of this type is pipelineable and can hold off its internal data until $\overline{OE}$ is asserted. The interface keeps the first data beat valid until the $\overline{BDIP}$ signal indicates that it should send out the next data. This interface type can function as an asynchronous interface. That is, a device with this ITYPE can be assigned to the $\overline{CSBOOT}$ region, which comes out of reset configured as an asynchronous region with seven wait states. In this case, the MCU doesn't latch the data to be read until the assigned number of wait states have elapsed and $\overline{OE}$ is asserted.
0110	Reserved.
0111	Region with fixed burst access capability (burst type 1) and synchronous $\overline{OE}$. Refer to **Figure 5-23** (but with a synchronous, not asynchronous, $\overline{OE}$) and to **Figure 5-24**. Devices with this type of interface are pipelineable and can hold off internal data until $\overline{OE}$ is asserted. The interface keeps the first data beat valid until the $\overline{BDIP}$ signal indicates that it should send out the next data. This interface type can function as an asynchronous interface. That is, a device with this ITYPE can be assigned to the $\overline{CSBOOT}$ region, which comes out of reset configured as an asynchronous region with seven wait states. In this case, the MCU doesn't latch the data to be read until the assigned number of wait states have elapsed and $\overline{OE}$ is asserted.
1000	Region with fixed burst access capability (burst type 2). Refer to **Figure 5-25**. This interface type uses the $\overline{LAST}$ timing protocol. Typically, this ITYPE is used for burst accesses to DRAM. This interface type may have an $\overline{OE}$ and may have a wait state counter, but the chip-select logic does not expect the device to have either and will never assert the $\overline{OE}$ signal. ($\overline{OE}$ can be provided by external logic if required, or a different ITYPE can be selected.) The device will drive out the data after the number of wait states it requires. The interface keeps the first data beat valid for only one clock. Any access to a device with this type of interface must be made using chip selects, and the ACKEN bit in the option register for the chip select must be set. Because this type cannot hold off its internal data until the data bus is available, an access to a region of this type cannot be pipelined with a previous access to the same or a different region. (That is, the address of an access to this region cannot appear on the external bus before the data for the previous access.) The address for the second access can overlap the data for the first access, however. In addition, if an access to this region is followed by an access to a pipelineable region, the second access is pipelined. This interface type can function as an asynchronous interface. That is, a device with this ITYPE can be assigned to the $\overline{CSBOOT}$ region, which comes out of reset configured as an asynchronous region with seven wait states. In this case, the MCU doesn't latch the data to be read until the assigned number of wait states have elapsed and $\overline{OE}$ is asserted.
1001	Synchronous region (no burst) with synchronous $\overline{OE}$, as with ITYPE 3, but with early overlapping of accesses to the region. Refer to **Figure 5-21**. This type of interface must be able to pipeline another access to it one clock cycle before it drives valid data out on a read or receives data on a write for the previous access.
1010–1111	Reserved.

5.5.13.2 Turn-Off Times for Different Interface Types

The turn-off time for asynchronous devices is equal to the time for $\overline{OE}$ to negate plus the time for device's outputs to go to a high-impedance state. For devices with an

ITYPE of zero, turn-off time is less than or equal to one clock cycle. For devices with an ITYPE of one, turn-off time is two clock cycles.

The turn-off time of asynchronous devices must be taken into account in systems that pipeline accesses to devices controlled by chip selects with accesses to devices that are not under chip select control. Otherwise, external bus contention can result.

The turn off time for synchronous devices is equal to the time from the rising edge of the device's clock to the time the device's outputs are in a high-impedance state. This turn off time must be less than or equal to one clock period.

5.5.13.3 Interface Type and $\overline{BI}$ Generation

During a burst access to a region under chip-select control that does not support burst accesses, the chip-select unit asserts the $\overline{BI}$ signal internally. Only regions with an ITYPE of five, seven, and eight support burst accesses.

CAUTION

It is recommended that the $\overline{BI}$ pin not be asserted during accesses to memory regions controlled by chip selects; instead, the chip-select unit will generate the $\overline{BI}$ signal internally when appropriate.

5.5.14 Chip-Select Operation Flowchart

Figure 5-14 illustrates the operation of the chip-select logic for external accesses.

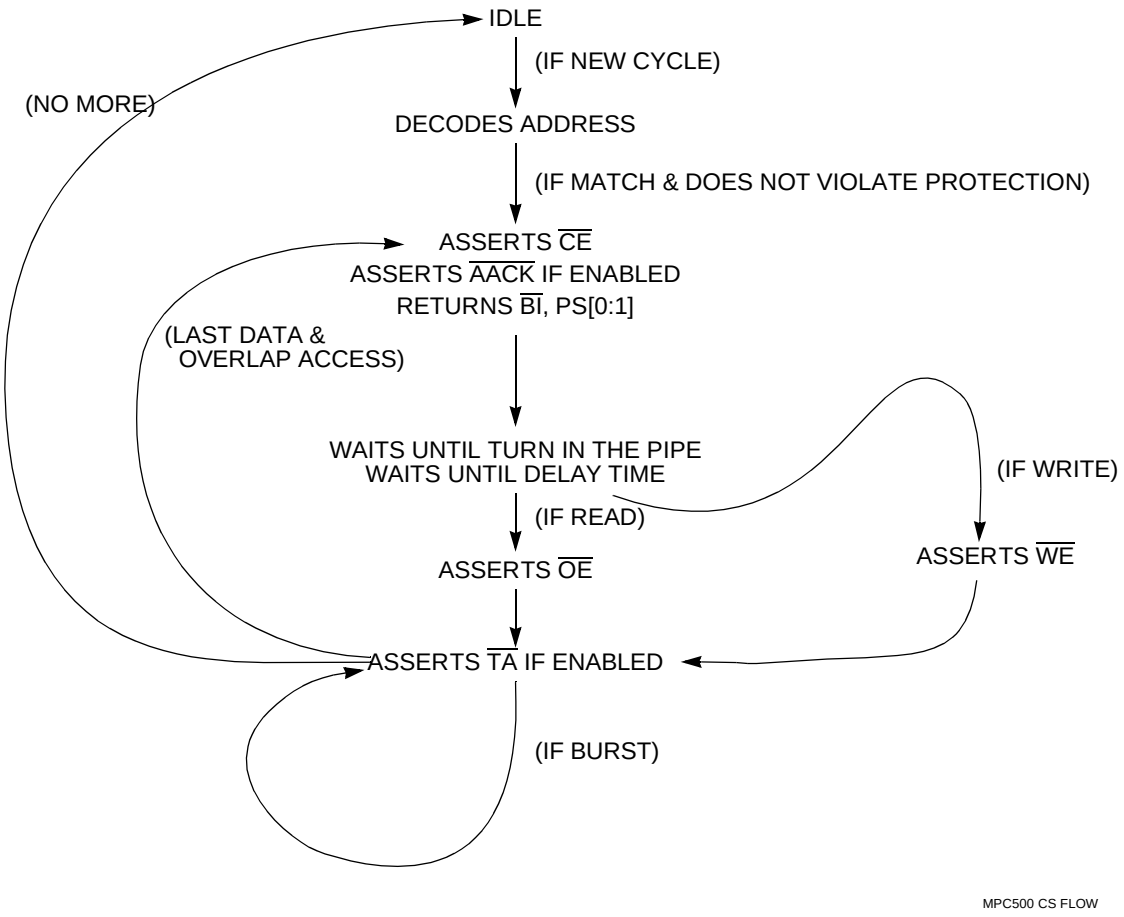


Figure 5-14 Chip-Select Operation Flowchart

5.5.15 Pipe Tracking

The chip-select module supports pipelined accesses to external devices. Up to two cycles can be pending in the chip-select module.

The chip-select unit supports pipelined reads for certain types of interfaces. Pipelined writes are not supported. **Table 5-28** summarizes the chip-select pipelining of read and write accesses.

Table 5-28 Pipelined Reads and Writes

First Access	Second Access	Pipelining Supported
Read	Read	Yes
Write	Read	Yes
Read	Write	No
Write	Write	No

The following subsections explain which types of interfaces permit pipelining of read accesses. Pipelining of consecutive accesses to the same region is discussed first, followed by pipelining of consecutive accesses to different regions.

5.5.15.1 Pipelined Accesses to the Same Region

The chip-select unit overlaps consecutive accesses to the same region, provided the following conditions are met:

- The second access is a read
- The region is pipelineable (as determined by its ITYPE)
- The $\overline{TA}$ signal is generated by the chip-select logic (ACKEN = 1).

When these conditions are met, the address (and $\overline{CE}$ assertion) for the second access can overlap the data phase of the first access.

Figure 5-15 illustrates the concept of overlapped accesses to the same region. (Note that the diagram cannot be assumed to be accurate in timing.)

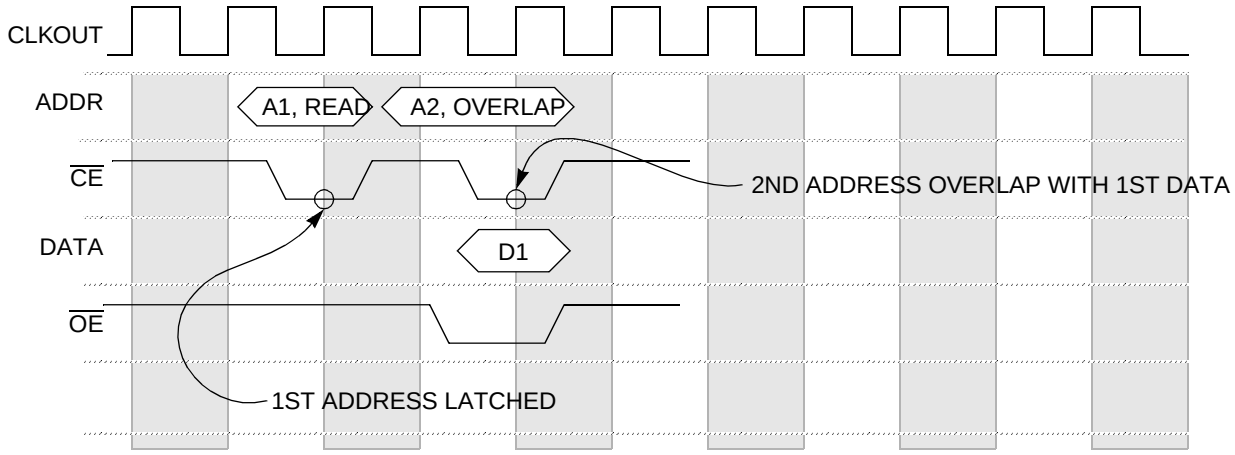


Figure 5-15 Overlapped Accesses to the Same Region

NOTE

If the region is programmed to return its own handshaking signals (ACKEN = 0), the chip-select logic does not know whether the device has an address latch (hence, whether the device is programmable). The chip-select control logic takes this into account and asserts the $\overline{CE}$ of the second access only after $\overline{AACK}$ has been asserted for the first access.

5.5.15.2 Pipelined Accesses to Different Regions

The chip-select unit supports pipelined accesses to different memory regions, depending on the properties of the two regions. The chip-select module tracks the incoming cycles and uses the information in the option registers to control the assertion of the $\overline{CE}$, $\overline{WE}$, and $\overline{OE}$ signals.

For the chip-select module to pipeline accesses to two different regions, the first region must be pipelineable; otherwise, the chip-select unit waits for the first access to complete ($\overline{TA}$ asserted) before beginning the second access.

Figure 5-16 uses two synchronous devices (ITYPE = 2) to illustrate this pipelining case. In this example, the first access is to a four-wait-state region, and the second access is to a region with zero wait states. (For a second region with wait states, the pipelining is similar except the data of the second region takes more time to be available on the bus if the second region cannot hold off its internal data.) The example is intended to show when the $\overline{CE}$ (or address phase) and the data phase of the second access can be given to the region. It assumes the device(s) in the first region is pipelineable, and both accesses are initiated by the same bus master.

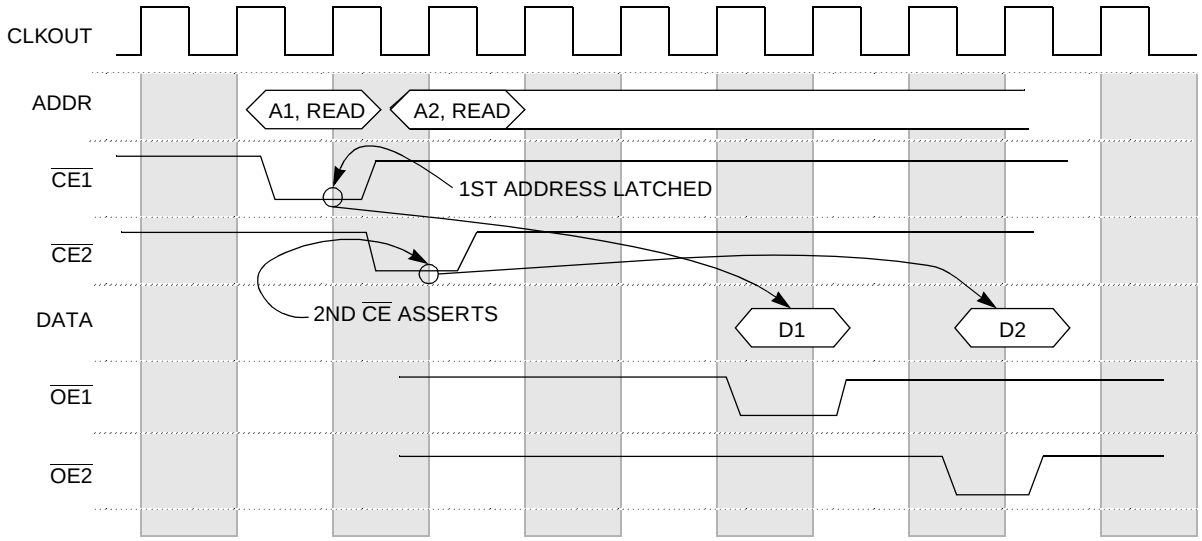


Figure 5-16 Pipelined Accesses to Two Different Regions

1. If both regions are under chip-select control, the delays of both regions are known to the chip-select logic, and the interface type of the first region supports pipelining, then the second access (if a read) can be pipelined with the first.
2. For any two consecutive accesses, if the latency of either region is not known to the chip-select logic, the two accesses are pipelined only if the second access is a read access to a region with an interface type that can hold off the data until the data bus is available (See **Table 5-27**).
   For example, suppose the first access is to a region that supplies its own $\overline{TA}$ signal, the second access is to another region with ITYPE = 8, and $\overline{TA}$ is returned by the chip-select logic for the second access. In this case, the chip-select logic must hold off the second access until the first access is completed because the second region may not be able to hold off its data without an $\overline{OE}$.
   On the other hand, suppose the first access is to a region that supplies its own $\overline{TA}$ signal, the second access is to another region with ITYPE = 3 (synchronous $\overline{OE}$) and $\overline{TA}$ is returned by the chip-select logic for the second access. In this

case, the second region can hold off its data until its $\overline{OE}$ is asserted. The chip-select module can pipeline the second access (if a read) with the first access after it has received the $\overline{AACK}$ signal for the first access. The chip-select logic asserts the $\overline{CE}$ of the second access while the data phase of the first access is still in progress, if the second access is issued before the first access is completed.

3. If the first access is to a region that is not under chip-select control (external glue logic generates all control and handshake signals for the region, as for a DRAM controller, for example), and the second access is to a region that is under chip-select control, the chip-select module does *not* pipeline the second access with the first.
4. If the first access is to a region under chip-select control and the second access is a read access to a region that is not under chip-select control, the external glue logic designer must decide whether to pipeline the second access with the first. The decision depends on system requirements and on the interface type of the region that is not under chip-select control.
5. If the first access is a burst read access to a burstable region and the second is a read access to another region, the chip-select module pipelines the second read if the second access is to a region with an interface type that is pipelineable and can hold off its data. If ITYPE = 8 for the second region, the chip-select module does not pipeline the second access with the first.
6. If the first access is to a synchronous region, and the second access is to an asynchronous region, the chip-select module does *not* pipeline the accesses.
7. If the first access is to an asynchronous region, the chip-select module does *not* pipeline the second access with the first, since both the external address and data bus must be available for the first access until it is completed. If the first region requires an extra clock to turn off its buffer, the chip-select logic allows an extra clock for the region.

5.5.16 Chip-Select Timing Diagrams

The diagrams in this section show the different device interfaces that the chip-select module supports. Where applicable, the diagrams indicate how the various signals (address, data, and chip-select signals) are correlated.

CAUTION

The user must not assume that $\overline{CE}$ is always asserted simultaneously with $\overline{TS}$. Depending on the state of the pipeline (which depends on the interface types of the devices being accessed), the chip-select unit may delay asserting $\overline{CE}$ until one or more clock cycles after $\overline{TS}$ is asserted.

5.5.16.1 Asynchronous Interface

An external device with an asynchronous interface requires the address and the chip select signals ($\overline{CE}$, $\overline{OE}$, and $\overline{WE}$) to be valid until the end of the access. The next access to the same device must wait for the previous access to complete. No overlap

of accesses is allowed. **Figure 5-17** and **Figure 5-18** illustrate the asynchronous interface for read and write accesses. For the asynchronous write, the external memory latches the data when $\overline{WE}$ is asserted.

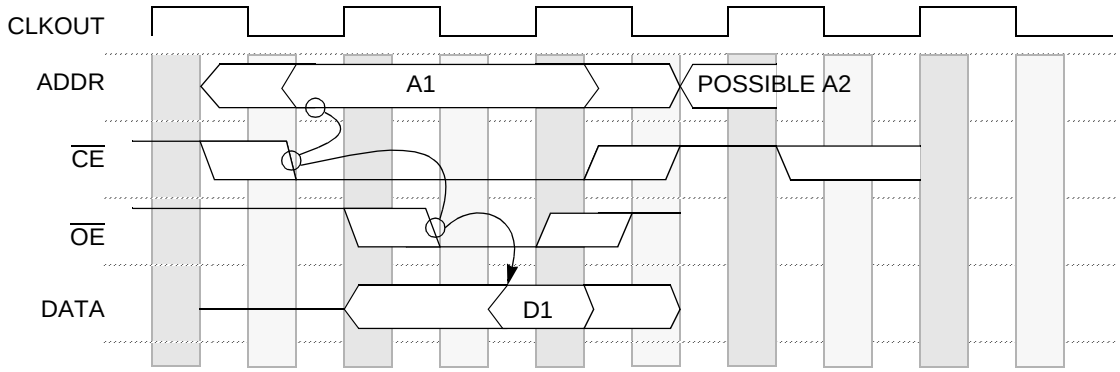


Figure 5-17 Asynchronous Read (Zero Wait States)

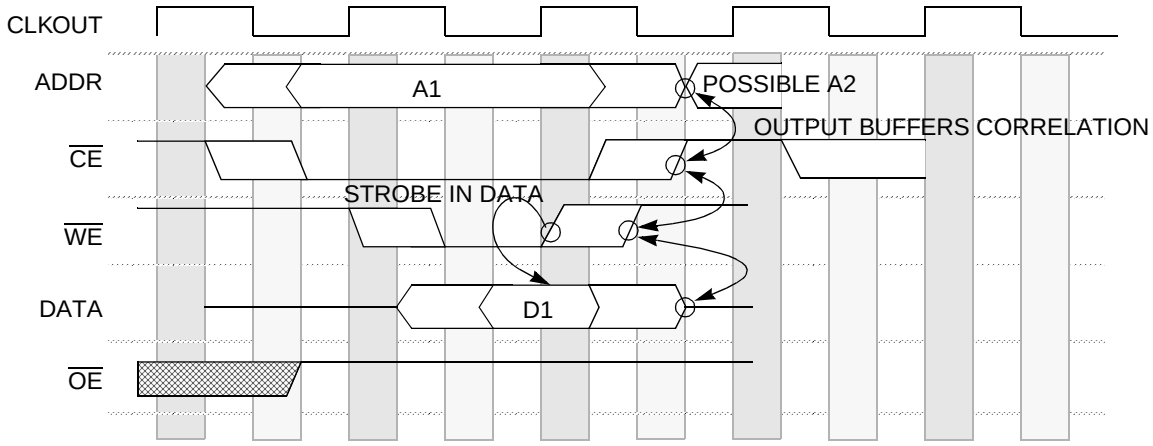


Figure 5-18 Asynchronous Write (Zero Wait States)

5.5.16.2 Asynchronous Interface with Latch Enable

Devices with an address latch enable signal, such as the Motorola MCM62995A memory chip, also support unlatched asynchronous read and write interfaces as shown in **Figure 5-17** and **Figure 5-18**. The chip-select module supports this type of device in the unlatched asynchronous mode only.

5.5.16.3 Synchronous Interface with Asynchronous $\overline{OE}$

Devices with ITYPE = 2 have a synchronous interface with an asynchronous output enable. Devices of this type clock the address and the data on the rising edge of CLKOUT. On a read access, these devices drive the data out as soon as the $\overline{OE}$ is asserted. In addition, the interface has the ability to latch the address so the next access to the same device can be overlapped with the previous access.

Figure 5-19 and **Figure 5-20** illustrate reads and writes for devices with this type of interface.

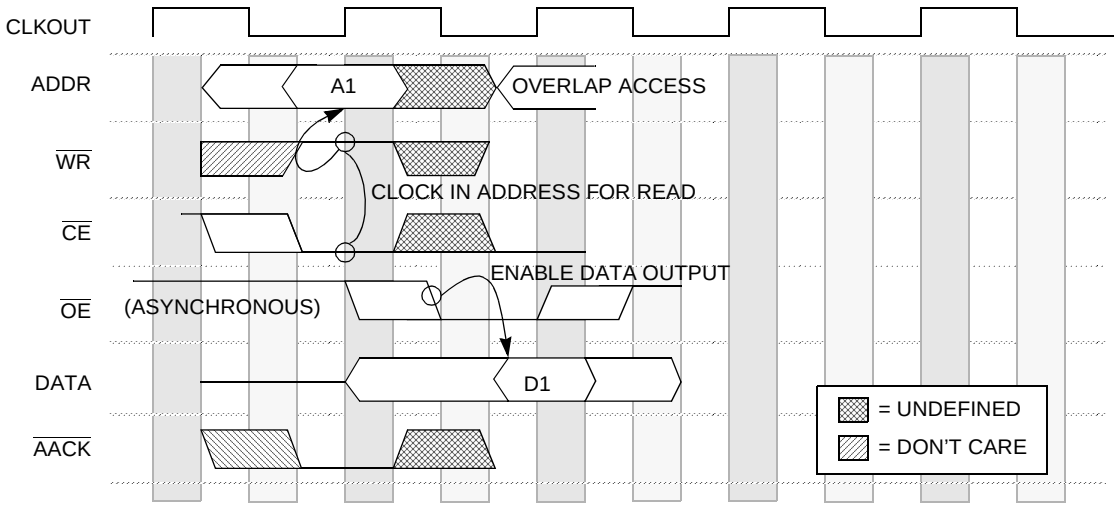


Figure 5-19 Synchronous Read with Asynchronous $\overline{OE}$ (Zero Wait States)

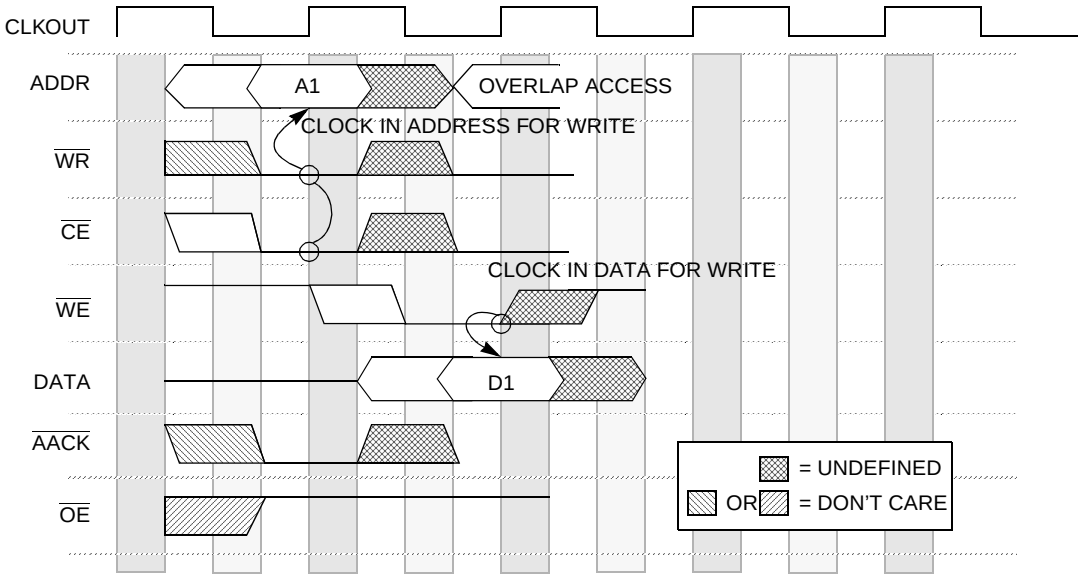


Figure 5-20 Synchronous Write (Zero Wait States)

5.5.16.4 Synchronous Interface with Early Synchronous $\overline{OE}$

Devices with ITYPE = 3 have a synchronous interface with a synchronous output enable. $\overline{OE}$ is asserted, at the earliest, one clock cycle after $\overline{CE}$. The synchronous $\overline{OE}$ should be sampled by the external device using the rising edge of its clock signal.

For read accesses, the early $\overline{OE}$ signal allows the responding device to prepare for the next data cycle. If $\overline{OE}$ is asserted, the device can prepare to drive the next data or re-

fill its internal data queue. If $\overline{OE}$ is not asserted, the device can place the data lines in a high-impedance state for fast relinquishing of the data bus.

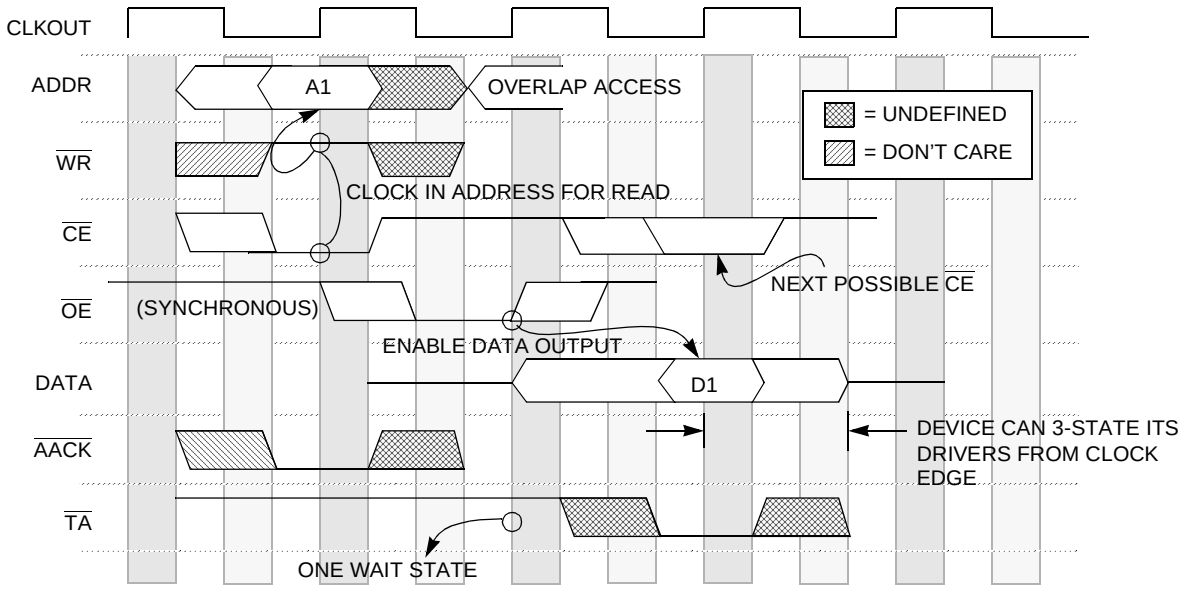


Figure 5-21 Synchronous Read with Early $\overline{OE}$ (One Wait State)

5.5.16.5 Synchronous Interface with Synchronous $\overline{OE}$, Early Overlap

Devices with ITYPE = 9 are synchronous with a synchronous output enable. They are different from devices with ITYPE = 3 in that they support early overlapping of accesses. That is, the region is capable of accepting a second address one clock cycle before the data phase of the first access terminates. Notice in **Figure 5-22** that $\overline{CE}$ is asserted one clock cycle earlier than in the previous example (**Figure 5-21**).

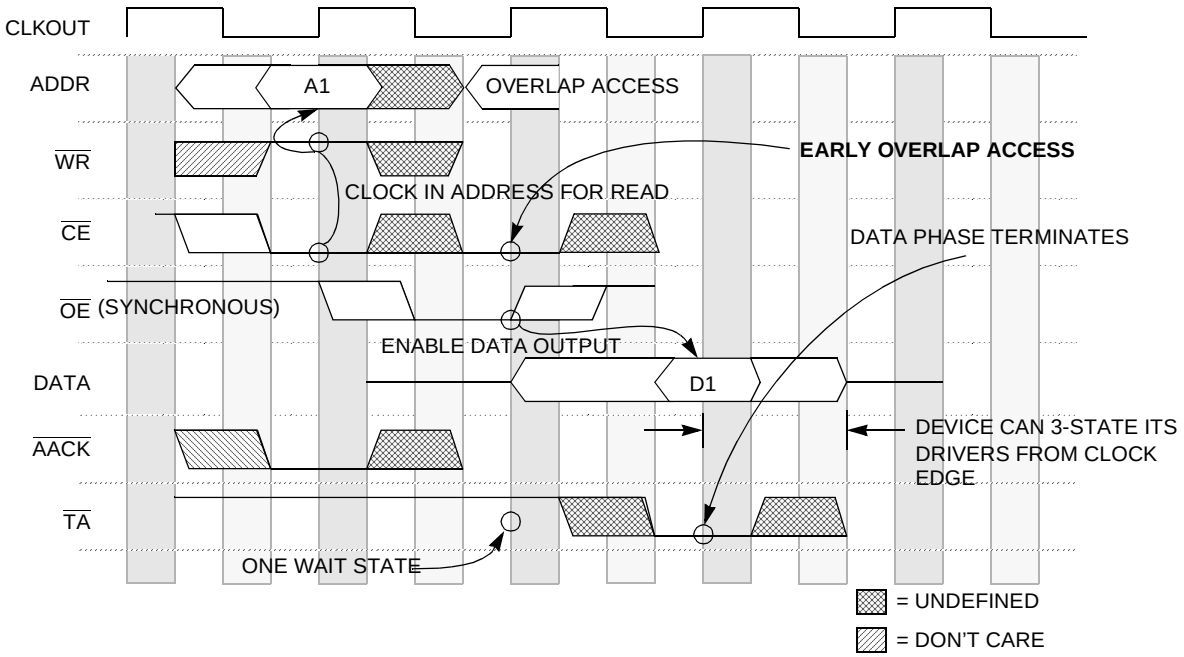


Figure 5-22 Synchronous Read with Early Overlap (One Wait State)

5.5.16.6 Synchronous Burst Interface

The chip-select module supports two types of burst interfaces. The type 1 burst interface uses the output enable and the write enable to control the data being driven out or received. The type 1 burst interface also requires a $\overline{\text{BDIP}}$ signal to control when the region should output the next beat of the burst.

For the read case, the type 2 burst interface does not require an output enable signal. Instead, it uses a $\overline{\text{LAST}}$ signal. When this signal is asserted at the rising edge of the clock, the type 2 burst device places its output buffers in a high-impedance state following the clock edge. The $\overline{\text{CE}}$ of the type 2 burst must be valid for the duration of the device's access latency or wait states. This type of device also requires a signal with timing similar to that of the $\overline{\text{TS}}$ signal. The interface may or may not contain an $\overline{\text{OE}}$ signal.

Any access to a device with type 2 burst interface must be made using chip selects, and the ACKEN bit in the option register for the chip select must be set.

NOTE

The $\overline{\text{LAST}}$ and $\overline{\text{BDIP}}$ signals share the same pin. The LST bit in the SIU module configuration register (SIUMCR) specifies whether the pin uses timing for the $\overline{\text{LAST}}$ signal (LST = 1) or the $\overline{\text{BDIP}}$ signal (LST = 0).

Type 1 and type 2 burst interfaces both have address latches, so the address of the next access to the device can be overlapped with the previous access. That is, the

address of an access does not need to be valid after the address has been latched at the rising edge of the clock.

For type 1 burst interfaces with an asynchronous $\overline{OE}$, the ITYPE field in the appropriate chip-select option register should be programmed to 0b0101. For type 1 burst interfaces with a synchronous $\overline{OE}$, this field should be programmed to 0b0111. For type 2 burst interfaces, ITYPE should be programmed to 0b1000.

Figure 5-23 and **Figure 5-24** show a read and write access, respectively, to a type 1 burst interface. Note in **Figure 5-23** that the $\overline{OE}$ is asynchronous (ITYPE = 5).

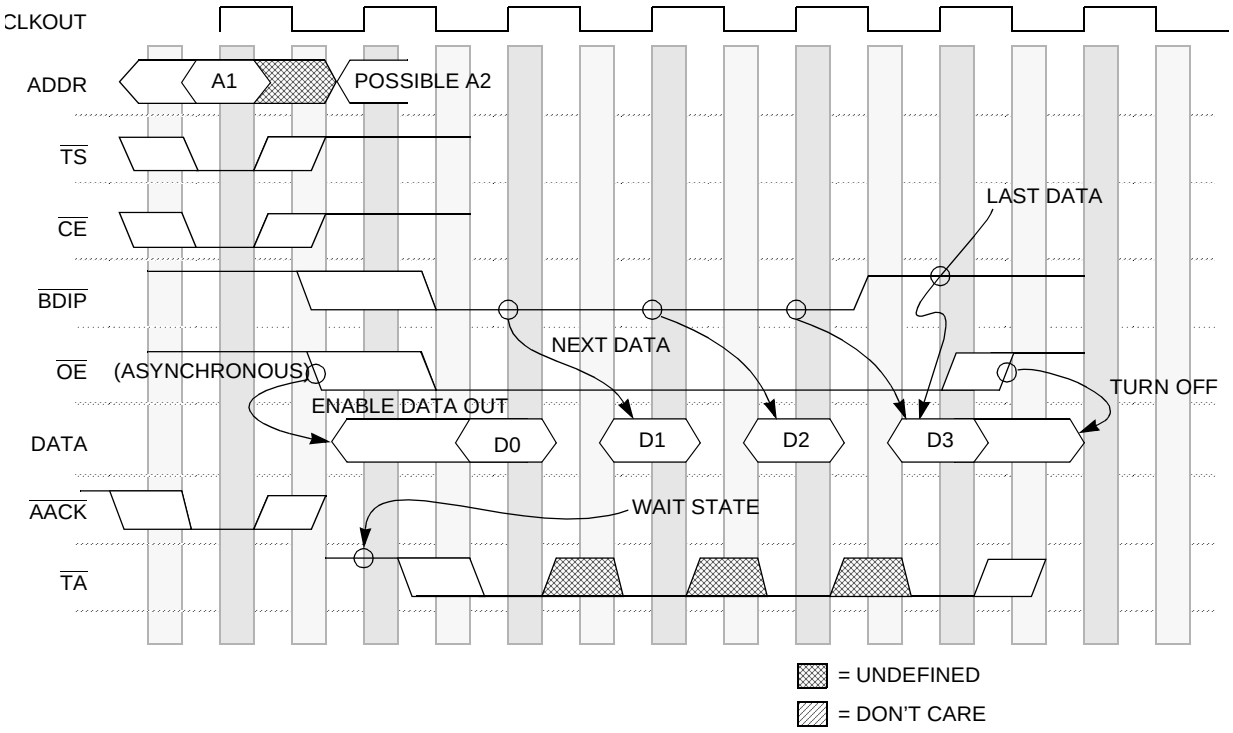


Figure 5-23 Type 1 Synchronous Burst Read Interface

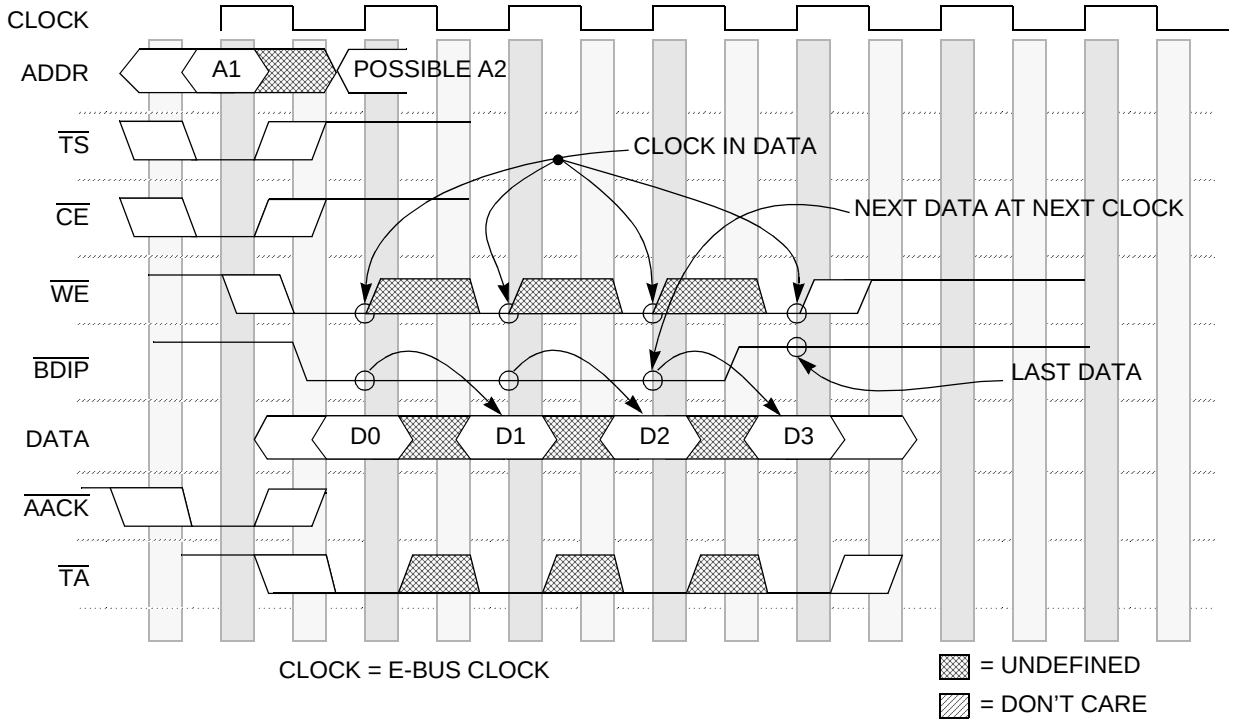


Figure 5-24 Type 1 Synchronous Burst Write Interface

Figure 5-25 shows a read access to a type 2 burst interface (ITYPE = 8). Note that an output enable signal is not required for this type of interface. Instead, the interface uses the $\overline{\text{LAST}}$ signal.

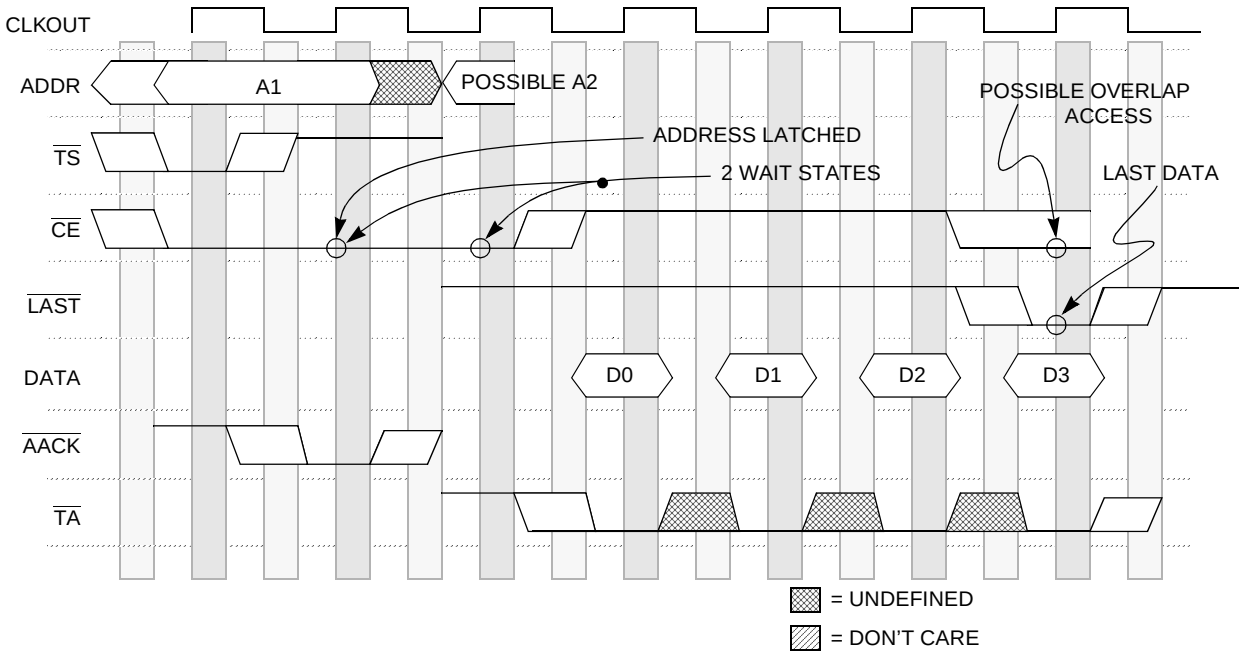


Figure 5-25 Type 2 Synchronous Burst Read Interface

5.5.17 Burst Handling

The chip-select module supports burst accesses, with four data beats per burst. The following paragraphs describe how the chip-select module handles some of the more complex cases.

- For a single-word access to a burstable region, the chip-select module asserts $\overline{OE}$ (on a read) or $\overline{WE}$ (on a write) for only one word. The burstable region may require an early termination signal such as $\overline{LAST}$. The EBI is expected to provide the early termination indication to the region.
- For fixed burst access to a burstable region, since all burstable types supported by the chip-select module allow fixed burst accesses, the chip-select module keeps the $\overline{OE}$ or $\overline{WE}$ asserted for the length of four words unless the cycle is terminated early.
- For a burst access to a non-burstable region, the chip-select module asserts the burst inhibit indication to the EBI and treats the access as a single-word access.
- For a fixed-burst access to a burstable small port (16-bit) device, the chip-select module keeps the $\overline{OE}$ or $\overline{WE}$ valid until the EBI terminates the burst. Depending on the starting address of the burst, the EBI breaks the access into two or more cycles and increments the address appropriately. The small port device is expected to wrap as specified in 5.4 External Bus Interface.
- For a single-word access to a device with a small port, the chip-select module always performs a single access to the small port device and indicates to the EBI that the device has a 16-bit port. If more data is needed, the EBI requests the chip selects to perform another access to the device to complete the transfer.

5.5.18 Chip-Select Reset Operation

The data bus configuration word specifies how the MCU is configured at reset. **Table 5-29** summarizes the data bus configuration bits that affect chip selects.

Table 5-29 Data Bus Configuration Word Settings for Chip Selects

Bit(s)	Configuration Function Affected	Description
0	Address bus/chip selects	0 = CS[0:11]/ADDR[0:11] configured as address pins 1 = CS[0:11]/ADDR[0:11] configured as chip-select pins (default value)
1	Exception prefix (vector table location)	0 = Vector table begins at 0x0000 0000 1 = Vector table begins at 0xFFF0 0000 (default value)
2	Burst mode type	0 = Type 1 burst mode — uses BDIP timing (default value) 0 = Type 2 burst mode — uses LAST timing
3	ITYPE of boot device	0 = Boot device ITYPE = 0x08 (Synchronous burst) 1 = Boot device ITYPE = 0x01 (Asynchronous — default value)
4	Port size of boot device	0 = Boot device has 16-bit port (default value) 1 = Boot device has 32-bit port
6:8	TA delay for CSBOOT	000 = 0 wait states 001 = 1 wait state 010 = 2 wait states 011 = 3 wait states 100 = 4 wait states 101 = 5 wait states 110 = 6 wait states 111 = 7 wait states (default value)

The boot region can be a ROM or flash EPROM. At power-on, it is assumed that no writing to the region is needed until the chip-select logic has been configured. Thus, no WE is needed at power-on time. The boot device can be internal or external memory. If internal memory, the boot device is not under chip-select control. If the boot device is located externally, the chip-select logic decodes the address of the access and enables the CE and OE of the boot device appropriately. If the external boot device has a type 2 burst interface, the LAST signal must be supplied by the EBI.

Note that at power-on, the boot region may be located at the uppermost or lowermost 1 Mbyte of the address range. The CSBOOT base address (specified in the BA field of CSBTBAR) can be reset to 0xFFF0 0000 or 0x0000 0000 accordingly. The chip-select logic asserts the CSBOOT signal for the entire 1-Mbyte range if the access is to external boot memory.

While RESET is asserted, the MCU drives the chip-select pins high (negated) to avoid a possible data bus conflict.

5.6 Clock Submodule

The system clock provides timing signals for the IMB2 and for an external peripheral bus. The MCU drives the system clock onto the external bus on the CLKOUT pin. The main timing reference for the MPC500 family is a 4-MHz crystal. The system operating frequency is generated through a programmable phase-locked loop. The PLL is programmable in integer multiples of 4 MHz to generate operating frequencies of 16 MHz

to 44 MHz. These frequencies can be divided by powers of two to generate other frequencies.

If the crystal ceases to function, the loss of oscillator (LOO) bit is set and the PLL is forced to operate in the self-clocked mode (SCM). This mode provides a system clock frequency of approximately 4 MHz. The exact frequency depends on the voltage and temperature of the CPU, but is optimized for nominal operating conditions.

The PLL can be bypassed by grounding the V_{DDSN} pin. Note that in this case, the input frequency needs to be twice the desired operating system frequency. With V_{DDSN} grounded, the multiplication factor (MF) bits in the system clock control register (SCCR) no longer have any effect on the system frequency, but the reduced frequency (RFD) bits and the low-power mode (LPM) bits do have an effect.

Three different low-power modes are available to minimize standby power usage. Normal operation or one of the three low-power modes is selected by programming the LPM bits in the SCCR.

The clock submodule also provides a clock source for the PowerPC time base and decrementer. The oscillator, time base, and decrementer are powered from the keep alive power supply (VDDKAP1). This allows the time base to continue incrementing even when the main power to the MCU is off. While the power is off, the decrementer also continues to count. The power-down wakeup pin (PDWU) can be programmed to signal an external power-on reset circuit to enable power to the system whenever the MSB of the decrementer changes from a zero to a one.

Figure 5-26 is a block diagram of the SIU clock module.

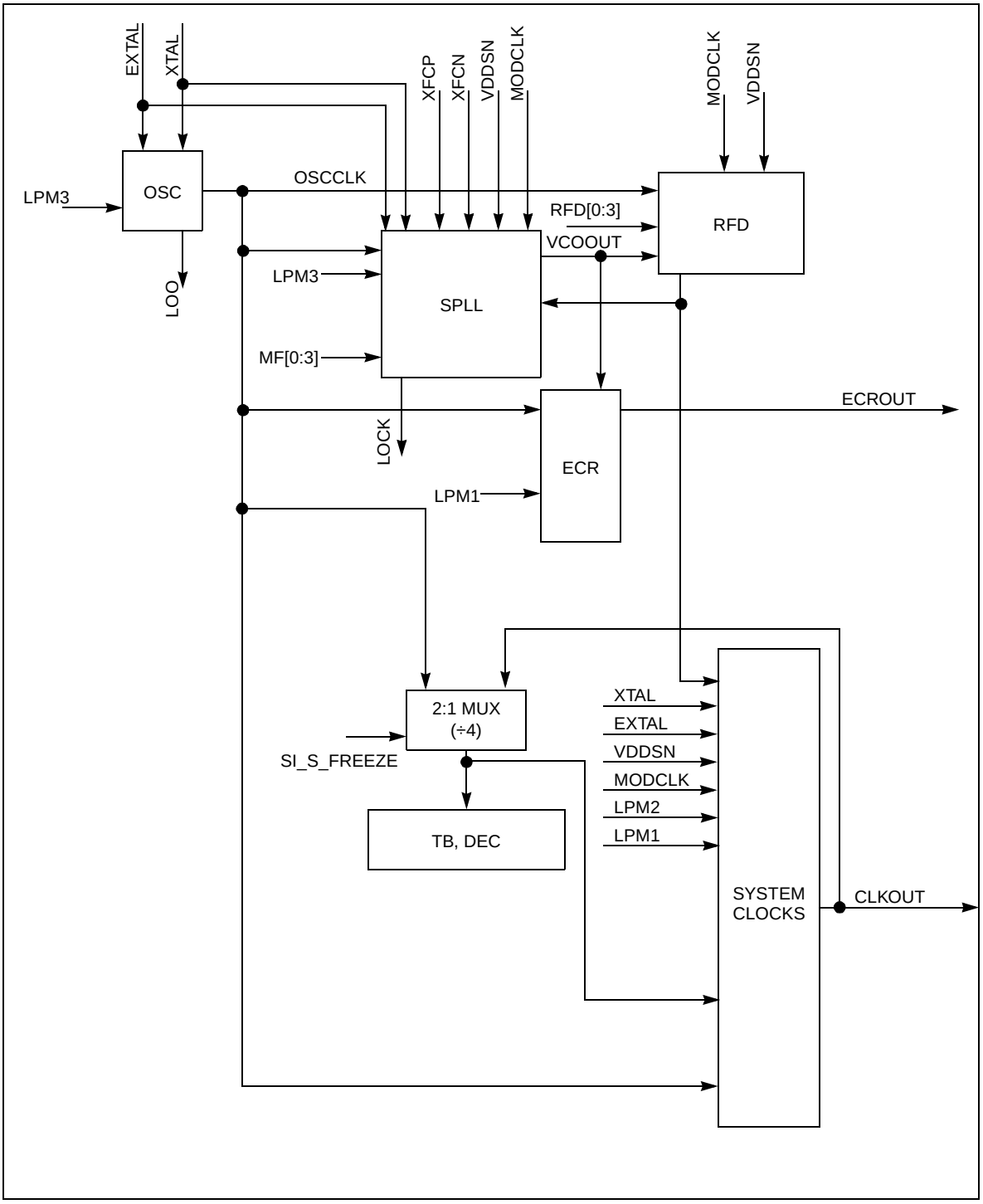


Figure 5-26 SIU Clock Module Block Diagram

5.6.1 Clock Submodule Signal Descriptions

Table 5-30 describes the signals used by the clock module.

Table 5-30 Clocks Module Signal Descriptions

Mnemonic	Name	Direction	Description
CLKOUT	System clock out	Output	System clock. Used as the bus timing reference by external devices.
EXTAL, XTAL	Crystal oscillator	Input, Output	Connections for external crystal to the internal oscillator circuit. An external oscillator should serve as input to the EXTAL pin, when used.
XFCN, XFCP	External filter capacitor	Input	These pins are used to add an external capacitor to the filter circuit of the phase-locked loop.
MODCLK	Clock mode select	Input	The state of this input signal during reset selects the source of the system clock. Refer to **5.6.3 System Clock Sources**.
V_{DDSN}, V_{SSSN}	Synthesizer power	Input	These pins supply a quiet power source to the VCO.
ECROUT	Engineering clock reference output	Output	Buffered output of the crystal oscillator. The ECROUT output frequency is equal to the crystal oscillator frequency.
PLLL/DSDO	PLL lock status or debug output	Output	Phase-locked loop status output or debug output.
PDWU	Power-down wake-up	Output	Asserted or negated, respectively, by software setting or clearing the WUR bit in the SCLSR. Also asserted when decrementer counts down to zero. Can be used as power-down wakeup to external power-on reset circuit.

5.6.2 Clock Power Supplies

The power supply for each block of the clock submodule is shown in **Table 5-31**.

Table 5-31 Clock Module Power Supplies

Power Supply	Blocks
V_{DDI}	CLKOUT ECR PIT Clock RFD PLL (Digital)
VDDKAP1	Decrementer/Time Base Clock Oscillator SCCR SCCSR
V_{DDSN}	PLL (Analog)

To improve noise immunity, the PLL has its own set of power supply pins, V_{DDSYN} and GND_{SYN}. Only the charge pump and the VCO are powered by these pins.

The oscillator, system clock control register, and system clock control and status register are powered from the keep alive power supply (VDDKAP1) and V_{SSI}. In addition, VDDKAP1 powers the PowerPC time base and decrementer. This allows the time

base to continue incrementing at 1 MHz even when the main power to the MCU is off. While the power is off, the decrementer also continues to count and may be used to signal the external power supply to enable power to the system at specific intervals. This is the power-down wakeup feature.

5.6.3 System Clock Sources

The V_{DDSN} and MODCLK pins are used to configure the clock source for the MCU. The configuration modes are shown in **Table 5-32**.

Table 5-32 System Clock Sources

V_{DDSN}	MODCLK	PLL Options
1	1	Normal Operation
1	0	1:1 mode (CLKOUT frequency is equal to oscillator frequency)
0	1	PLL bypass mode (CLKOUT frequency is equal to one half the oscillator frequency)
0	0	Special test mode

When both pins are high, the CPU clocks are configured for normal operation and the PLL is fully programmable.

If MODCLK = 0 and V_{DDSN} = 1, then the PLL enters 1:1 frequency mode. In this mode, CLKOUT frequency is equal to the oscillator frequency and is not affected by the RFD bits. The oscillator can be driven by either an external crystal or an external clock source.

If V_{DDSN} = 0 and MODCLK = 1, then the PLL is disabled and bypassed. In this case, CLKOUT frequency is equal to one half the oscillator frequency. In this mode, the oscillator source must have a 50% duty cycle.

In each clock mode except bypass mode, CLKOUT frequency can be reduced by programming the RFD field to a non-zero value. Refer to 5.6.5 CLKOUT Frequency Control for details.

If V_{DDSN} = 0 and MODCLK = 0, then the CPU clocks are configured in special test mode. In this mode, the PLL and most of the clock generation circuitry are bypassed. This mode is intended for factory test only.

CAUTION

When the clock is in PLL bypass mode or special test mode, setting the LOLRE bit in the SCCR generates a loss-of-lock reset request (since the PLL is off). The LOLRE bit must not be set when the clock is in PLL bypass or special test mode.

5.6.4 Phase-Locked Loop

The phase-locked loop (PLL) is a frequency synthesis PLL that can multiply the reference clock frequency by a factor from 4 to 11, provided the system clock (CLKOUT)

frequency (when RFD = 0b000) remains within the specified limits. With a reference frequency of 4 MHz, the PLL can synthesize frequencies from 16 MHz to 44 MHz.

The output of the PLL can be divided down to reduce the system frequency with the reduced frequency divider (RFD). The RFD is not contained in the feedback loop of the PLL, so changing the RFD bits does not affect PLL operation.

Note that the system frequency programmed should not exceed the operating frequency of any of the parts in the target system.

Figure 5-27 shows the overall block diagram for the PLL. Each of the major blocks shown is discussed briefly below.

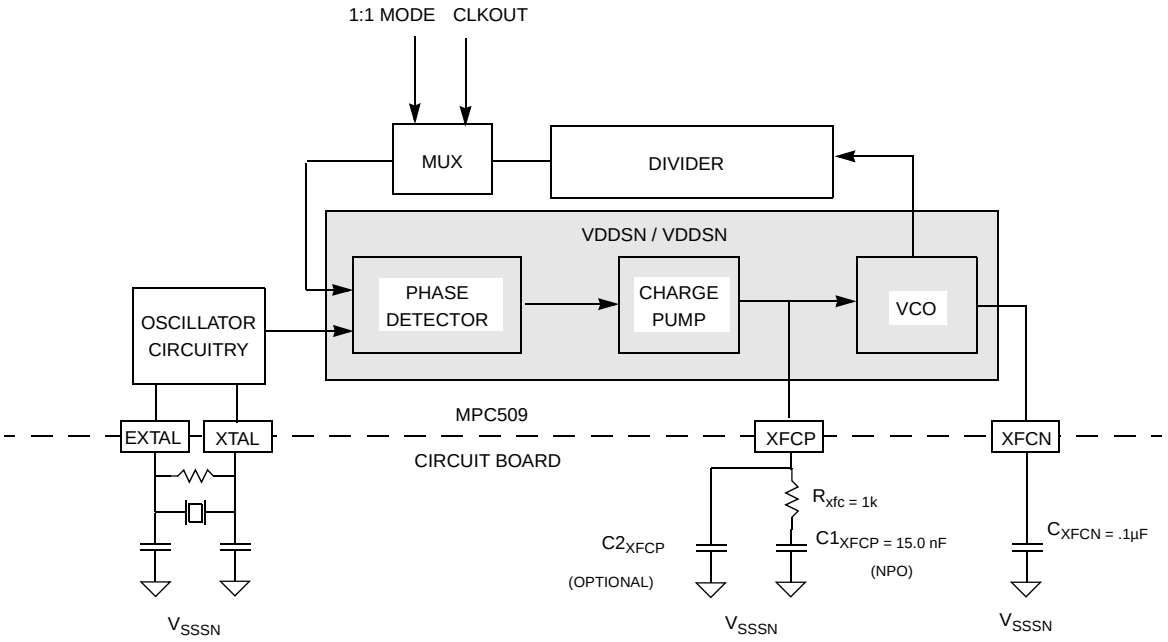


Figure 5-27 Phase-Locked Loop Block Diagram

5.6.4.1 Crystal Oscillator

The crystal oscillator has one 10-M¾ resistor and two external 36-pf capacitors connected to the EXTAL and XTAL pins, as shown in **Figure 5-28**. The internal oscillator is designed to work best with a 4-MHz crystal. Crystal start-up times depend on the value of the resistor. The start-up time can be reduced by reducing the value of the resistor.

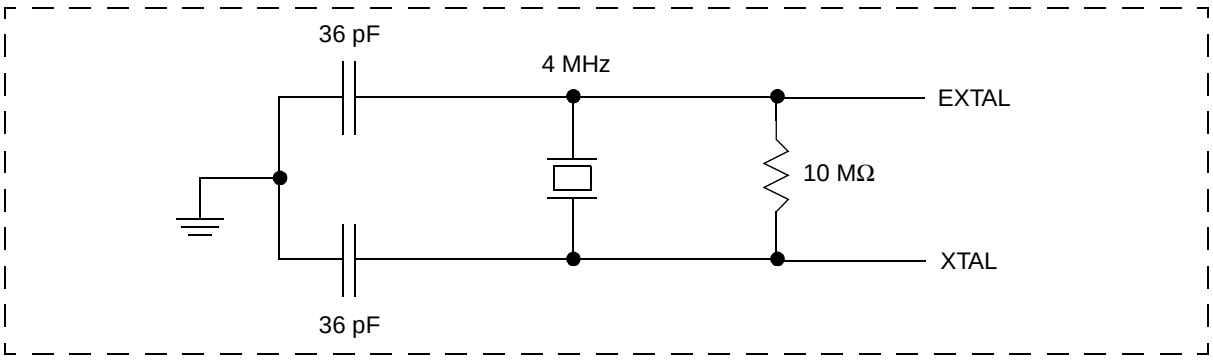


Figure 5-28 Crystal Oscillator

5.6.4.2 Phase Detector

The phase detector compares both the phase and frequency of the reference clock (*oscclk* in **Figure 5-27**) and the feedback clock. The reference clock comes from either the crystal oscillator or an external clock source. The feedback clock comes from either CLKOUT (the system clock) in 1:1 mode or the VCO output divided down by the MF divider in normal mode.

The phase detector pulses either the UP or DOWN signal, depending on the relative phase of the two clocks. If the falling edge of the feedback clock lags the falling edge of the reference clock, then the UP signal is pulsed. If the falling edge of the feedback clock leads the falling edge of the reference clock, then the DOWN signal is pulsed. The width of these pulses relative to the reference clock is dependent on how much the two clocks lead or lag each other.

5.6.4.3 Charge Pump and Loop Filter

The UP and DOWN signals from the phase detector control whether the charge pump applies or removes charge, respectively, from the loop filter. The loop filter is shown in **Figure 5-29**. The filter network is external to the chip and can be replaced if necessary.

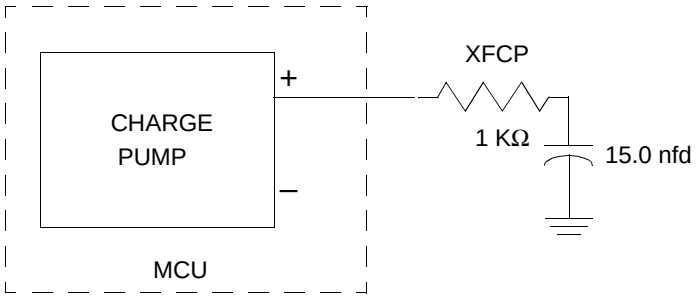


Figure 5-29 Charge Pump with Loop Filter Schematic

5.6.4.4 VCO

The VCO uses a single-ended design with an external capacitor to increase noise immunity. The voltage on XFCP controls the VCO output frequency. The frequency-to-voltage relationship (VCO gain) is positive, and the output frequency is twice the maximum target system frequency.

5.6.4.5 Multiplication Factor Divider

The multiplication factor divider (MFD) divides down the output of the VCO and feeds it back to the phase detector (when the PLL is not operating in 1:1 mode). The phase detector controls the VCO frequency (via the charge pump and loop filter) such that the reference and feedback clocks have the same frequency and phase.

Thus, the input to the MFD, which is also the output of the VCO, is at a frequency that is the reference frequency multiplied by the same amount that the MFD divides by. For example, if the MFD divides the VCO frequency by six, then the PLL will be frequency locked when the VCO frequency is six times the reference frequency.

The presence of the MFD in the loop allows the PLL to perform frequency multiplication, or synthesis. When the PLL is operating in 1:1 mode, the MFD is bypassed and the effective multiplication factor is one. Refer to 5.6.5 CLKOUT Frequency Control for details on setting system clock frequency with the MF and RFD bits.

5.6.4.6 Clock Delay

Besides frequency synthesis, the PLL must also align the phase of (i.e., phase lock) the reference and system clocks to ensure proper system timing. Since the purpose of the RFD is to allow the user to change the system frequency without forcing the PLL to re-lock, the feedback clock must originate before the RFD (i.e., the output of the VCO).

The clock delay is a chain of gates that approximates the delay through the RFD, clock generation circuits, metal routing and the CLKOUT driver. This approach does not allow for precise phase alignment. System applications must not rely on precise phase alignment between the reference and system clocks when the PLL is operating in normal (frequency synthesis) mode. In 1:1 mode, however, the RFD is disabled. The feedback clock comes directly from the CLKOUT pin, and true phase lock is achieved.

5.6.5 CLKOUT Frequency Control

The multiplication factor (MF) and reduced frequency divide (RFD) fields in the SCCR determine the system clock (CLKOUT) frequency. **Table 5-33** summarizes the available CLKOUT frequencies with a 4-MHz crystal.

Table 5-33 CLKOUT Frequencies with a 4-MHz Crystal[1]

RFD[0:3]	CLKOUT (Hz)							
	MF = X000 (x4)	MF = X001 (x5)	MF = X010 (x6)	MF = X011 (x7)	MF = X100 (x8)	MF = X101 (x9)	MF = X110 (x10)	MF = X111 (x11)
0 = 0000 (÷ 1)	16.000 M	20.000 M	24.000M	28.000 M	32.000 M	36.000 M	40.000 M	44.000 M
1 = 0001 (÷ 2)	8.000 M	10.000 M	12.000 M	14.000 M	16.000 M	18.000 M	20.000 M	22.000 M
2 = 0010 (÷ 4)	4.000 M	5.000 M	6.000 M	7.000 M	8.000 M	9.000 M	10.000 M	11.000 M
3 = 0011 (÷ 8)	2.000 M	2.500 M	3.000 M[2]	3.500 M	4.000 M	4.500 M	5.000 M	5.500 M
4 = 0100 (÷ 16)	1.000 M	1.250 M	1.500 M	1.750 M	2.000 M	2.250 M	2.500 M	2.750 M
5 = 0101 (÷ 32)	0.500 M	0.625 M	0.750 M	0.875 M	1.000 M	1.125 M	1.250 M	1.3750 M
6 = 0110 (÷ 64)	0.250 M	0.313 M	0.375 M	0.438 M	0.500 M	0.563 M	0.625 M	0.688 M
7 = 0111 (÷ 128)	0.125 M	0.156 M	0.188 M	0.219 M	0.250M	0.281 M	0.313 M	0.344 M
8 = 1000 (÷ 256)	62.500 K	78.125 K	93.750 K	0.109 M	0.125 M	0.141 M	0.156 M	0.172 M
9 = 1001 (÷ 512)	31.250 K	39.063 K	46.875 K	54.688 K	62.500 K	70.313 K	78.125 K	85.938 K
10 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K
11 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K
12 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K
13 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K
14 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K
15 = 1010 (÷ 1024)	15.625 K	19.531 K	23.438 K	27.344 K	31.250 K	35.156 K	39.063 K	42.969 K

NOTES:
1. Settings resulting in CLKOUT frequencies in the shaded areas should not be used in the MPC509.
2. Default setting.

Whenever clock reset is asserted, the MF bits are set to 0x2 (multiply by six), and the RFD bits are set to 0x3 (divide by eight). These values program the PLL to generate the default system frequency of 3 MHz when a 4-MHz crystal is used.

5.6.5.1 Multiplication Factor (MF) Bits

The MF bits determine the operating frequency of the PLL. The 4-MHz crystal reference frequency is multiplied by an integer from 4 to 11, depending on the value of the MF bits, resulting in a PLL frequency of 16 MHz to 44 MHz. **Table 5-34** summarizes the effect of the MF bits.

Table 5-34 Multiplication Factor Bits

MF Field (Binary)	Multiplication Factor	PLL Frequency (with 4-MHz Reference)
x000	4	16 MHz
x001	5	20 MHz
x010	6	24 MHz
x011	7	28 MHz
x100	8	32 MHz
x101	9	36 MHz
x110	10	40 MHz
x111	11	44 MHz

Note that the PLL frequency is equal to the CLKOUT frequency when the RFD bits are programmed to 0b0000 (divide by one). Note also that the value of MF0 is ignored. However, this bit should be written to zero in case it is used in future implementations.

CAUTION

The MF bits must not be programmed to a value that requires the VCO to operate at greater than 180 MHz. (F_{VCO} = 4 x MF factor x F_{REF}.) Specifically, if the reference crystal frequency is 5 MHz, the MF settings of X110 (times 10) and X111 (times 11) must be avoided.

The MF bits can be read and written at any time. However, the MF bit field can be write-protected by setting the MF lock (MPL) bit in the SCSLR.

Changing the MF bits causes the PLL to lose lock. If the loss-of-lock reset enable bit (LOLRE) is set, the loss-of-lock condition causes the clock module to signal a reset condition to the reset controller. The reset controller may wait for the PLL to lock before negating reset. Thus, the PLL can still be out of lock when $\overline{\text{RESETOUT}}$ is negated. After changing the MF bits, software should monitor the system PLL lock status (SPLS) bit in the SCSLR to determine lock status.

The RFD bits should always be written to a value of 0x1 or greater before changing the MF bits to ensure the system frequency does not exceed the system's design margin, since the VCO overshoots in frequency as it tries to compensate for the change in frequency. For example, to change from the default system frequency to 16 MHz, write the RFD bits to 0x1, then write the MF bits to 0x0. After the PLL locks, write the RFD bits to 0x0.

When the PLL is operating in one-to-one mode, the multiplication factor is set to one and MF is ignored.

Figure 5-27 shows how the PLL uses the MF bits to multiply the input crystal frequency. The output of the VCO is divided down to generate the feedback signal to the phase comparator. The MF bits control the value of the divider in the PLL feedback loop. The phase comparator determines the phase shift between the feedback signal

and the reference clock. This difference results in either an increase or decrease in the VCO output frequency.

5.6.5.2 Reduced Frequency Divider (RFD[0:3])

The RFD bits control a prescaler at the output of the PLL. The reset state of the RFD bits is 0x3, which divides the output of the VCO by eight.

These bits can be changed without affecting the PLL's VCO, i.e., no re-lock delay is incurred. All changes in frequency are synchronized to the next falling edge of the current system clock.

Table 5-35 summarizes the possible values for the RFD bits.

Table 5-35 Reduced Frequency Divider Bits

RFD Field (Binary)	Divider
0000	1
0001	2
0010	4
0011	8
0100	16
0101	32
0110	64
0111	128
1000	256
1001	512
1010	1024
1011	1024
1100	1024
1101	1024
1110	1024
1111	1024

These bits can be read at any time. They should be written only when the system PLL lock status bit (SPLS) is set. Writing the RFD bits, especially to 0x0, when the PLL is not locked can cause the clock frequency to surpass the system operating frequency. Software is responsible for monitoring the SPLS bit and preventing a write to RFD[0:3] while the PLL is out of lock.

The RFD bits should always be written to a value of 0x1 or greater before changing the MF bits to ensure the system frequency does not exceed the system's design margin since the VCO overshoots in frequency as it tries to compensate for the change in frequency. The RFD bits should be changed to their final value only after the MF bits have been written to their final value and PLL lock at the new frequency has been established. For example, to change from the default system frequency to 16 MHz,

write the RFD bits to 0x1, then write the MF bits to 0x0. After the PLL locks, write the RFD bits to 0x0.

The RFD bits can be protected against further writes by setting the RFD lock (RFDL) bit in the SCSLR register.

NOTE

The RFD bits do not affect clock frequency when the system clock is operating in 1:1 mode.

5.6.6 Low-Power Modes

The clock module provides one normal operating mode and three low-power modes. The low-power mode (LPM) bits in the SCCR select one of these four modes. When one of the three low-power modes is selected, the EBI prevents the CPU from starting any more bus cycles, but allows the current bus cycle to terminate. At the end of the current bus cycle, the appropriate clocks are stopped and the EBI continues operation as defined for the low-power mode selected.

Note that in debug mode, the crystal and the PLL are not shut down, but continue to run and provide clocks to the debug module.

The LPM bits can be protected against further writes by setting the LPM lock (LPML) bit in the SCLSR register.

5.6.6.1 Normal Mode

The normal operating mode, state 0x0, is the state out of clock reset. This is also the state the bits go to when the low-power mode exit signal arrives.

5.6.6.2 Single-Chip Mode

Mode 0x1 is single-chip mode. In this mode, CLKOUT is turned off. This mode can be selected when the MCU is used by itself and does not need to provide a system clock. Turning off CLKOUT saves power and improves electromagnetic compatibility. The low-power mode exit signal is the logical OR of the external reset pin, the $\overline{\text{IRQ}}$[0:1] pins (if LPMM = 1), the decrementer interrupt, and the PIT interrupt.

Since the oscillator and PLL are still running and locked, the low-power mode exit signal must be a minimum of two system clock cycles and exiting this state does not incur a PLL lock time.

5.6.6.3 Doze Mode

Mode 0x2 is doze mode. In this state, not only is CLKOUT turned off, but also all internal clocks are turned off. However, the oscillator and the PLL continue to operate normally. The low-power mode exit signal is the logical OR of the external reset pin, the $\overline{\text{IRQ}}$[0:1] pins (if LPMM = 1), the decrementer interrupt, and the PIT interrupt. Since the oscillator and PLL are still running and locked, the low power mode exit signal must be a minimum of two system clock cycles and exiting this state does not incur a PLL lock time.

5.6.6.4 Sleep Mode

Mode 0x3 is sleep mode. In this state, *all* clocks are turned off, including the oscillator and the PLL. The low-power mode exit signal is the logical OR of the external reset pin and the IRQ[0:1] pins (if LPMM = 1). The decrementer interrupt and the PIT interrupt are not active in this mode. Since all clocks are stopped, this signal is asynchronous. Exiting state 0x3 requires the normal crystal start-up time plus PLL lock time or time-out.

5.6.6.5 Exiting Low-Power Mode

Table 5-36 summarizes the events that cause the MCU to exit from each of the three low-power modes.

Table 5-36 Exiting Low-Power Mode

Event Causing Exit from Low-Power Mode	Mode 0x1	Mode 0x2	Mode 0x3
RESETOUT assertion	Yes	Yes	Yes
IRQ pin assertion (if LPMM = 1)	Yes	Yes	Yes
Decrementer interrupt	Yes	Yes	No
PIT interrupt	Yes	Yes	No

The low-power mode mask (LPMM) bit in the SCCR is used to mask the IRQ[0:1] pins to the low-power mode exit logic. When the LPMM bit is zero, the IRQ[0:1] pins are disabled from causing an exit from any of the low-power modes. When the LPMM bit is a one, the IRQ[0:1] pins are enabled to cause an exit from any of the low-power modes.

When a low level occurs at the IRQ[0:1] pins and the LPMM bit is a one, the LPM bits are cleared and the low-power mode exit sequence begins. If the LPMM bit = 1, then the low-power mode exit sequence is started even if a low-power mode is not selected.

The time required to exit the low-power modes depends on which mode was selected. For modes 1 and 2, the delay from the exit signal being asserted to the clocks starting up is two clock cycles of the frequency that the VCO was programmed to generate. The delay for mode 3 is the crystal start-up time plus the VCO lock time.

The LPMM bit can be read or written any time.

5.6.7 System Clock Lock Bits

The system clock lock and status register (SCLSR) contains several bits that lock the corresponding bits or fields in the system clock control register (SCCR). **Table 5-37** summarizes the lock bits and the fields that they control.

Table 5-37 System Clock Lock Bits

SCLSR Lock Bit	SCCR Field Affected
MPL	MF
LPML	LPM
RFDL	RFD

When a lock bit (MPL, LPML, or RFDL) is cleared, writes to the corresponding bit or field in the SCCR (MF, LPM or RFD, respectively) take effect. When the lock bit is set, however, writes to the corresponding bit or field in the SCCR have no effect. All other bits in the SCCR are unaffected.

The MPL, LPML, and RFDL bits can be written to zero as many times as required. Only a clock reset can clear one of these bits, however, once it is written to a one. In freeze mode, the lock bits can be written to a one or to a zero at any time.

5.6.8 Power-Down Wake Up

PDWU (power-down wake up) is an output signal used to signal an external power supply to enable power to the system. PDWU can be asserted by the decrementer counting down to zero or by the CPU setting the wake-up request (WUR) bit in the SCLSR.

The WUR bit controls the state of the PDWU pin directly. The WUR bit is set when the CPU writes a one to it or when the MSB of the decrementer changes from a zero to a one. WUR is cleared when the CPU writes a zero to it. (Note that to clear the bit, it is *not* necessary to read the bit as a one before writing it as a zero, as is required to clear most status bits.)

Note that the WUR bit is not affected by resets and its value should remain as long as the keep-alive power is valid. At keep-alive reset, the WUR bit is in an unknown state.

5.6.9 Time Base and Decrementer Support

The time base is a timer facility defined by the PowerPC architecture. It is a 64-bit free-running binary counter which is incremented at a frequency determined by each implementation of the time base. There is no interrupt or other indication generated when the count rolls over. The period of the time base depends on the driving frequency. The time base is not affected by any resets and should be initialized by software.

The decrementer is a 32-bit decrementing counter defined by the PowerPC architecture. The decrementer causes an interrupt, unless masked by MSR[EE], when it passes through zero.

The time base and decrementer use the stand-by power supply, VDDKAP1. This allows them to be used while normal power is off. The time base and decrementer also continue to function in all low-power modes except sleep mode (LPM = 0b11), in which the oscillator is turned off.

The state of the decrementer and time base after standby power is restored is indeterminate. The decrementer runs continuously after power-up (unless the decrementer clock enable bit is cleared). System software is necessary to perform any initialization. The decrementer is not affected by reset and continues counting while reset is asserted.

Reads and writes of the time base and decrementer are restricted to special instructions. Refer to SECTION 3 CENTRAL PROCESSING UNIT and to the *RCPU Reference Manual* (RCPURM/AD) for instructions on reading and writing the time base and decrementer.

5.6.9.1 Time Base and Decrementer Clock Source

The frequency source is the crystal oscillator divided by four

The clock source for the time base and decrementer is the crystal oscillator divided by four. With a 4-MHz oscillator frequency, the period for the time base is:

$$T_{TB} = 2^{64} / 1MHz = 1.8 \times 10^{13} \text{ seconds}$$

which is approximately 585,000 years.

With the same clock source, the period for the decrementer is:

$$T_{DEC} = 2^{32} / 1MHz = 4295 \text{ seconds}$$

which is approximately 71.6 minutes.

5.6.9.2 Time Base/Decrementer and Freeze Assertion

The assertion of the global freeze signal can stop the clock to the time base and decrementer if the SIUFRZ bit in the SIUMCR (0x8007 FC00) is set. The actual freezing of the clock source occurs at the falling edge of the clock.

5.6.9.3 Decrementer Clock Enable (DCE) Bit

The decrementer clock enable (DCE) bit in the SCCR enables or disables the clock source to the decrementer. The default state is to have the clock enabled. The actual clock source is determined by the TBS bit. The DCE bit does not affect the decrementer until after the next increment time, as determined by the clock source.

5.6.10 Clock Resets

The following reset conditions cause the internal clock reset signal to be asserted: external reset, loss-of-oscillator (when LOORE is set), and loss-of-lock (when LOLRE is set). Clock reset causes the clock circuitry, including the PLL, oscillator, SCCR, and SCLSR to be reset.

Note that all reset sources cause normal reset processing to occur, as described in **5.8 Reset Operation**. However, only the reset sources mentioned above (external reset, loss-of-oscillator, and loss-of-lock) result in clock reset.

5.6.10.1 Loss of PLL Lock

The system PLL lock status (SPLS) in the SCLSR indicates the current lock status of the PLL. When the SPLS bit is clear, the PLL is not locked. When the SPLS bit is set, the PLL is locked. The SPLS bit can be read anytime. It can be written only during special test mode.

In PLL bypass mode and special test mode, this bit is forced high to indicate a lock condition.

The loss-of-lock reset enable (LOLRE) bit in the SCCR indicates how the clocks should handle a loss of lock indication (SPLS asserted). When LOLRE is clear, clock reset is not asserted if a loss of lock indication occurs. When LOLRE is set, clock reset is asserted when a loss of lock indication occurs. The reset module may wait for the PLL to lock before negating reset (see 5.8 Reset Operation). The LOLRE bit is cleared whenever clock reset is asserted and may be re-initialized by software.

CAUTION

When the clock is in PLL bypass mode or special test mode, setting the LOLRE bit in the SCCR generates a loss-of-lock reset request (since the PLL is off). The LOLRE bit must not be set when the clock is in PLL bypass or special test mode.

The system PLL lock status sticky bit (SPLSS) in the SCLSR must be initialized by software. After the bit is set by software, any out-of-lock indication clears the SPLSS bit, even if the out-of-lock indication is active while the setting takes place. The bit remains clear until software again sets it. At clock reset, the state of the SPLSS bit is zero, since the PLL has not achieved lock.

5.6.10.2 Loss of Oscillator

The loss-of-oscillator (LOO) status bit in the SCLSR indicates the absence of an input frequency on the EXTAL pin. A frequency below 125 kHz causes the loss-of-oscillator circuitry to assert the LOO bit and force the PLL into self-clocked mode. A frequency above 500 kHz causes the loss-of-oscillator circuitry to negate the LOO bit, and the PLL operates normally. The LOO bit can be read any time. It can be written only in special test mode.

The loss-of-oscillator reset enable (LOORE) bit in the SCCR indicates how the clock module should handle a loss-of-oscillator condition (LOO asserted). When LOORE is clear, clock reset is not asserted if a loss-of-oscillator indication occurs. When LOORE is set, clock reset is asserted when a loss-of-oscillator indication occurs. The reset module may wait for the PLL to lock before negating reset (see 5.8 Reset Operation). The LOORE bit is cleared when clock reset is asserted and may be re-initialized by software.

Note that a loss of oscillator forces the PLL to go out of lock and into the self-clocked mode (SCM), regardless of the state of the LOORE bit.

5.6.11 System Clock Control Register (SCCR)

The SCCR controls the operation of the PLL. It is powered by VDDKAP1. The SCCR is not affected by reset conditions that do not cause clock reset. Clock reset (caused by loss-of-oscillator, loss-of-lock, or external reset) causes the register to be reset as indicated in the diagram.

SCCR — System Clock Control Register **0x8007 FC50**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED			LPMM	0	DCE	LOL-RE	LOOR E	0	MF				RESERVED		
CLOCK RESET:															
0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED						LPM		RESERVED				RFD			
CLOCK RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table 5-38 SCCR Bit Settings

Bit(s)	Name	Description
0:2	—	Reserved
3	LPMM	Low-power mode mask 0 = $\overline{\text{IRQ}}$[0:1] pins cannot be used to wake up from LPM 1 = $\overline{\text{IRQ}}$[0:1] pins can be used to wake up from LPM
4	—	Reserved
5	DCE	Decrementer clock enable 0 = Clock to decrementer is disabled 1 = Clock to decrementer is enabled
6	LOLRE	Loss-of-lock reset enable 0 = Loss of lock does not cause reset 1 = Loss of lock causes reset
7	LOORE	Loss-of-oscillator reset enable 0 = Loss of oscillator does not cause reset 1 = Loss of oscillator causes reset
8	—	Reserved
9:12	MF	Multiplication factor. In normal mode, the output of the VCO is divided down to generate the feedback signal to the phase comparator. The MF field controls the value of the divider in the PLL feedback loop. The MF and RFD fields determine the CLKOUT frequency. Refer to **Table 5-33**. X000 = x 4 X001 = x 5 X010 = x 6 X011 = x 7 X100 = x 8 X101 = x 9 X110 = x 10 X111 = x 11 Caution: The MF bits must not be programmed to a value that requires the VCO to operate at greater than 180 MHz. (F_{VCO} = 4 x MF factor x F_{REF}.) Specifically, if the reference crystal frequency is 5 MHz, the MF settings of X110 (times 10) and X111 (times 11) must be avoided.

Table 5-38 SCCR Bit Settings (Continued)

Bit(s)	Name	Description
13:21	—	Reserved
22:23	LPM	Low-power mode select bits. Refer to **Table 5-35** and **Table 5-36**. 00 = Normal operating mode 01 = Low-power mode 1 (single chip) 10 = Low-power mode 2 (doze) 11 = Low-power mode 3 (sleep) Since all clocks are stopped in sleep mode, exiting this mode requires the normal crystal start-up time plus the PLL lock time. Minimum length of the exit signal is two clocks in single-chip mode, three clocks in doze mode, and until the PLL is stable in sleep mode.
24:27	—	Reserved
28:31	RFD	Reduced-frequency divider. The RFD field controls a prescaler at the output of the PLL. In normal mode, the MF and RFD fields determine the CLKOUT frequency. (In bypass mode, only this field, and not the MF field, affects CLKOUT frequency. In one-to-one mode, this field has no effect.) Refer to **Table 5-33**. 0000 = ÷ 1 0001 = ÷ 2 0010 = ÷ 4 0011 = ÷ 8 0100 = ÷ 16 0101 = ÷ 32 0110 = ÷ 64 0111 = ÷ 128 1000 = ÷ 256 1001 = ÷ 512 1010 = ÷ 1024 1011 = ÷ 1024 1100 = ÷ 1024 1101 = ÷ 1024 1110 = ÷ 1024 1111 = ÷ 1024

5.6.12 System Clock Lock and Status Register (SCLSR)

The system clock lock and status register (SCLSR) contains lock and status bits for the PLL. It is powered by VDDKAP1. The SCLSR is not affected by reset conditions that do not cause clock reset. Clock reset (caused by loss-of-oscillator, loss-of-lock, or external reset) causes the register to be reset as indicated in the diagram.

SCLSR — System Clock Lock and Status Register **0x8007 FC54**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED				STME	MPL	LPML	RFDL	RESERVED						STMS	
CLOCK RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED							WUR	RESERVED					SPLSS	SPLS	LOO
CLOCK RESET:															
0	0	0	0	0	0	0	U	0	0	0	0	0	U	U	U

U = Unaffected by clock reset

Table 5-39 SCLSR Bit Settings

Bit(s)	Name	Description
0:3	—	Reserved
4	STME	System PLL test mode enable 0 = Test mode disabled 1 = Test mode enabled
5	MPL	MF lock 0 = Writes to MF field (in SCCR) allowed 1 = Writes to MF field have no effect
6	LPML	Low-power mode lock 0 = Writes to LPM bits allowed 1 = Writes to LPM bits have no effect
7	RFDL	Reduced-frequency divide lock 0 = Writes to RF bits allowed 1 = Writes to RF bits have no effect
8:13	—	Reserved
14:15	STMS	System PLL test mode select 00 = Normal operation 00, 01, 11 = Special test modes (for factory test only)
16:22	—	Reserved
23	WUR	Wake-up request 0 = PDWU pin forced low (request power off) 1 = PDWU pin forced high (request power on)
24:28	—	Reserved
29	SPLSS	System PLL lock status sticky bit 0 = PLL has gone out of lock since software last set this bit 1 = PLL has remained in lock since software last set this bit
30	SPLS	System PLL lock status 0 = PLL has not locked 1 = PLL has locked
31	LOO	Loss-of-oscillator status 0 = Clock detected 1 = Crystal not detected

5.7 System Protection

SIU system protection features include a periodic interrupt timer and a bus monitor.

Additional MPC509 system protection features include the PowerPC decrementer and time base, described in SECTION 3 CENTRAL PROCESSING UNIT, and a software watchdog, described in 6.4 Software Watchdog.

5.7.1 System Protection Features

- The bus monitor monitors any internal-to-external bus accesses. Four selectable response time periods are available, ranging from 16 to 256 system clock cycles. An internal bus error signal is generated if a bus time-out occurs.
- The periodic interrupt timer generates an interrupt after a period specified by the user.

5.7.2 System Protection Registers

Table 5-40 shows the SIU system protection registers.

Table 5-40 System Protection Address Map

Access	Address	Register
S/U	0x8007 FC40	Periodic Interrupt Control and Select Register (PICSR)
S/U	0x8007 FC44	Periodic Interrupt Timer Register (PIT)
S	0x8007 FC48	Bus Monitor Control Register (BMCR)

5.7.3 Periodic Interrupt Timer (PIT)

The periodic interrupt timer consists of a 16-bit counter clocked by the input oscillator signal divided by four. A 4-MHz system oscillator frequency results in a one-microsecond count interval. The input clock signal is supplied by the clock module. In order to ensure adequate range for the PIT, the input clock signal to the PIT must not exceed 4 MHz.

The 16-bit counter counts down to zero when loaded with a value from the PIT count (PITC) field in the PICSR. After the timer reaches zero, the PIT status (PS) bit is set and an interrupt is generated if the PIT interrupt enable (PIE) bit is set to one.

At the next input clock edge, the value in the PITC is loaded into the counter, and the process starts over. When a new value is loaded into the PITC field, the periodic timer is updated (i.e., the new value is loaded into the modulus counter), and the counter begins counting.

The software service routine should read the PS bit and then write it to zero to terminate the interrupt request. The interrupt request remains pending until the PS bit is cleared. If the counter reaches zero again before the interrupt service routine clears the PS bit, the interrupt request remains pending until PS is cleared.

Any write to the PITC stops the current countdown, and the count resumes with the new value in PITC. If the PITC is loaded with the value 0, the PIT counts for the maximum period.

If the PIT enable (PTE) bit is not set, the PIT is unable to count and retains the old count value. Reads of the PIT register have no effect on the value in the PIT.

Figure 5-30 is a block diagram of the PIT.

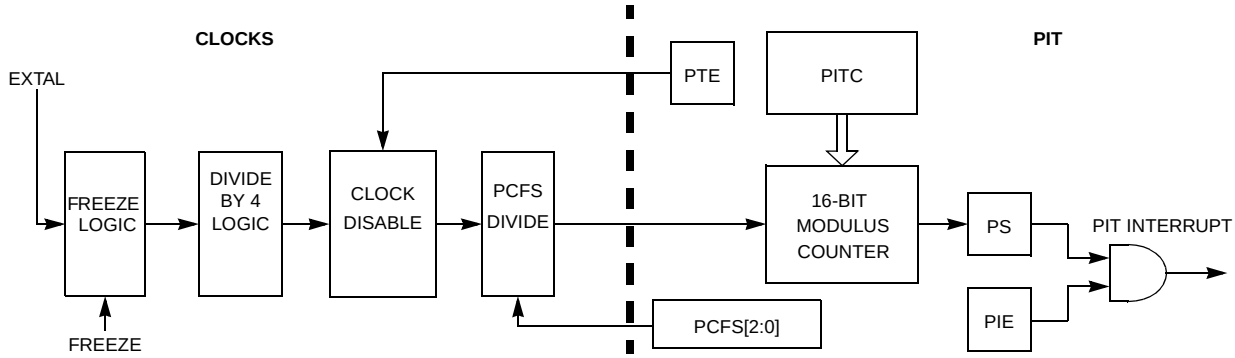


Figure 5-30 Periodic Interrupt Timer Block Diagram

5.7.3.1 PIT Clock Frequency Selection

The PIT clock frequency select (PCFS) field in the PICSR selects the appropriate frequency for the PIT clock source over a range of external clock or crystal frequencies. The bit encodings are shown in **Table 5-41**.

Table 5-41 PCFS Encodings

PCFS Encoding	Divide Input Frequency by:
0b000	4
0b001	8
0b010	16
0b011	32
0b100	64
0b101	Reserved
0b110	Reserved
0b111	Reserved

To achieve a PIT setting of approximately 1 MHz, program the PCFS field as shown in **Table 5-42**.

Table 5-42 Recommended Settings for PCFS[0:2]

Input Frequency Range	PCFS[0:2]
1 MHz < FREQ ≤ 4 MHz	0b000
4 MHz < FREQ ≤ 8 MHz	0b001
8 MHz < FREQ ≤ 16 MHz	0b010
16 MHz < FREQ ≤ 32 MHz	0b011
32 MHz < FREQ ≤ 64 MHz	0b100
Reserved	0b101
Reserved	0b110
Reserved	0b111

5.7.3.2 PIT Time-Out Period Selection

The PIT time-out period is determined by the input clock frequency, the divider specified in the PCFS field, and the timing count specified in the PITC field of the PICSR.

The time-out period is calculated as follows:

PIT period = PITC/(PIT frequency)

where the PIT frequency is equal to the PIT input clock frequency divided by a divisor determined by the PCFS bits, as specified in 5.7.3.1 PIT Clock Frequency Selection.

With a 4-MHz clock frequency and a PCFS value of 0b000 (divide by 4, reset value), this gives a range from 1 µs (PITC = 0x0001) to 65.5 ms (PITC = 0x0000).

Table 5-43 Example PIT Time-Out Periods

PITC Value	Time-Out Period[1]
1 (decimal)	1 µs
5 (decimal)	5 µs
10 (decimal)	10 µs
100 (decimal)	100 µs
1000 (decimal)	1.00 ms
10000 (decimal)	10.00 ms
50000 (decimal)	50.0 ms
FFFF (hex)	65.5 ms
0000 (hex)[2]	65.5 ms

NOTES:
1. After a time-out is signaled, some additional time may elapse prior to any observed action.
2. The count value associated with the maximum time-out is 0b0000.

5.7.3.3 PIT Enable Bits

The PIT enable (PTE) bit in the PICSR enables or disables the timer. When the timer is disabled, it retains its current value. When the timer is enabled, it resumes counting starting with the current value.

The periodic interrupt enable (PIE) bit in the PICSR enables or disables PIT interrupts. When this bit is cleared, the PIT does not generate any interrupts. The PIT continues to count even when interrupts are disabled.

5.7.3.4 PIT Interrupt Request Level and Status

The PIT interrupt request level (PITIRQL) field in the PIT/port Q interrupt level register (PITQIL) determines the level of PIT interrupt requests. Refer to 6.5.3.4 PIT/Port Q Interrupt Levels Register for a description of this register.

The PIT status (PS) bit is set when the PIT issues an interrupt request. This occurs when the modulus counter counts to zero. The PS bit is cleared by writing it to zero after reading it as a one. Attempting to write this bit to one has no effect.

5.7.3.5 Periodic Interrupt Control and Select Register

The periodic interrupt control and select register (PICSR) contains the interrupt status bit as well as the controls for the 16 bits to be loaded into a modulus counter. Reserved bits in this register return zero when read. This register can be read or written at any time.

PICSR — Periodic Interrupt Control and Select Register **0x8007 FC40**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	PTE	PIE	RESERVED		PCFS			RESERVED							PS
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
PITC															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

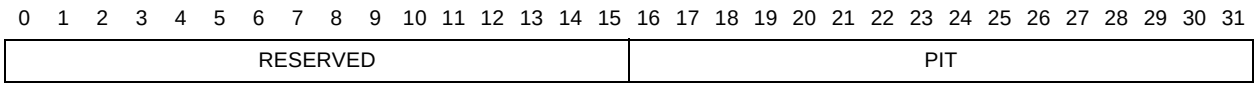
Table 5-44 PICSR Bit Settings

Bit(s)	Name	Description
0	—	Reserved
1	PTE	Periodic timer enable 0 = Disable decrementer counter 1 = Enable decrementer counter
2	PIE	Periodic interrupt enable 0 = Disable periodic interrupt 1 = Enable periodic interrupt Caution: Be sure the EE (external interrupts enable) bit in the MSR is cleared before changing the value of this bit.
3:4	—	Reserved
5:7	PCFS	PIT clock frequency select. To achieve PIT setting of approximately 1 MHz, program the PCFS field as shown in **Table 5-42**.
8:14	—	Reserved
15	PS	PIT status 0 = No PIT interrupt asserted 1 = Periodic interrupt asserted
16:31	PITC	Periodic interrupt timing count. Number of counts to load into the PIT.

5.7.3.6 Periodic Interrupt Timer Register

The periodic interrupt timer (PIT) register is a read-only register that shows the current value in the periodic interrupt down counter. Writes to this register have no effect. Reads of the register do not affect the counter.

PIT — Periodic Interrupt Timer Register **0x8007 FC44**



RESET: UNDEFINED

5.7.4 Hardware Bus Monitor

Typical bus systems require a bus monitor to detect excessively long data and address acknowledge response times. The MPC509 provides a bus monitor to monitor internal-to-external bus accesses on the E-bus. If the external bus pipeline depth is zero (all previous external bus cycles are complete), the monitor counts from transfer start to transfer acknowledge. Otherwise, the monitor counts from transfer acknowledge to transfer acknowledge.

If the monitor times out, transfer error acknowledge ($\overline{\text{TEA}}$) is asserted internally.

The bus monitor is always enabled (regardless of the value of the BME bit in the BMCR) while the internal freeze signal is asserted and debug mode is enabled, or while debug mode is enabled and the debug non-maskable breakpoint is asserted.

5.7.4.1 Bus Monitor Timing

The bus monitor timing (BMT) field in the BMCR allows the user to select one of four selectable response time periods. Periods range from 16 to 256 system clock cycles. The programmability of the time-out allows for a variation in system peripheral response time. The timing mechanism is derived from taps off a divider chain which is clocked by the system clock.

The time-out period should be set for the maximum total cycle time (including all beats of a burst, i.e., until $\overline{TA}$ is asserted for the final beat of a burst cycle), not for just the address phase or data phase of the cycle.

5.7.4.2 Bus Monitor Lock

The bus monitor lock (BMLK) bit in the BMCR is used to prevent inadvertent writes to the BMCR. Once BMLK is set, subsequent writes to the BMCR have no effect and result in a data error on the internal bus.

Writing a zero to BMLK after it has been set has no effect. A write to the BMCR before the lock bit is set can configure protected bits and set the BMLK in the same access.

The BMLK bit is cleared by reset. It can also be cleared by software while the internal FREEZE signal is asserted. Software can write BMLK to zero any number of times before writing it to one.

5.7.4.3 Bus Monitor Enable

The bus monitor enable (BME) bit in the BMCR enables or disables the operation of the bus monitor during internal-to-external bus cycles. Note that the bus monitor is always enabled while freeze is asserted and debug mode is enabled, or when debug mode is enabled and the debug non-maskable breakpoint is asserted, even if BME is cleared.

5.7.4.4 Bus Monitor Control Register

A diagram and description of the BMCR are provided below.

BMCR — Bus Monitor Control Register **0x8007 FC48**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED				BMLK	BME	BMT		RESERVED							
RESET:															
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5-45 BMCR Bit Settings

Bit(s)	Name	Description
0:3	—	Reserved
4	BMLK	Bus monitor lock 0 = Enable changes to BMLK, BME, BMT 1 = Ignore writes to BMLK, BME, BMT
5	BME	Bus monitor enable 0 = Disable bus monitor 1 = Enable bus monitor
6:7	BMT	Bus monitor timing. These bits select the time-out period, in system clocks, for the bus monitor. 00 = 256 system clocks 01 = 64 system clocks 10 = 32 system clocks 11 = 16 system clocks
8:31	—	Reserved

5.8 Reset Operation

Reset procedures handle system initialization and recovery from catastrophic failure. The MPC509 performs reset with a combination of hardware and software. The SIU determines whether a reset is valid, asserts control signals, performs basic system configuration based on hardware mode-select inputs, and then passes control to the CPU.

Reset is the highest-priority CPU exception. Any processing in progress is aborted by the reset exception and cannot be restarted. Only essential tasks are performed during reset exception processing. Other initialization tasks must be accomplished by the exception handler routine.

5.8.1 Reset Sources

The following sources can cause reset:

- External reset pin ($\overline{\text{RESET}}$)
- Loss of oscillator
- Loss of PLL lock
- Software watchdog reset
- Checkstop reset
- JTAG reset (external $\overline{\text{TRST}}$ pin)

All of these reset sources are fed into the reset controller. The reset status register (RSR) reflects the most recent source, or sources, of reset. (Simultaneous reset requests can cause more than one bit to be set at the same time.) This register contains one bit for each reset source. A bit set to logic one indicates the type of reset that last occurred.

Individual bits in the RSR can be cleared by writing them as zeros after reading them as ones. (Writing individual bits as ones has no effect.) The register can be read at all times. Assertion of the $\overline{\text{RESET}}$ pin clears all bits except the RESET bit.

RSR — Reset Status Register **0x8007 FC4C**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RE-SET	LOO	LOL	SW	CR	JTAG	RESERVED									

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															

Table 5-46 Reset Status Register Bit Settings

Bit(s)	Name	Description
0	RESET	If set, source of reset is the external $\overline{\text{RESET}}$ input pin. This pin should be asserted whenever V_{DD} is below V_{DDmin}.
1	LOO	If set, source of reset is a loss of oscillator. The clock module asserts loss-of-oscillator reset when the MCU is in low-power mode 3 or no clock signal is present on the EXTAL pin. If the clock module detects a loss-of-oscillator condition, erroneous external bus operation will occur if synchronous external devices use the MCU input clock. Erroneous operation can also occur if devices with a PLL use the MCU CLKOUT signal. This source of reset is masked by the loss-of-oscillator reset enable (LOORE) bit in the system clock control register (SCCR).
2	LOL	If set, the cause of reset is the loss of PLL lock. The clock module asserts loss-of-lock reset when the PLL detects a loss of lock and the loss-of-lock reset enable bit is set in the system clock control register (SCCR). If the PLL detects a loss of lock condition, erroneous external bus operation will occur if synchronous external devices use the MCU input clock. Erroneous operation can also occur if devices with a PLL use the MCU CLKOUT signal. This source of reset is masked by the loss-of-lock reset enable (LOLRE) bit in the system clock control register.
3	SW	If set, source of reset is a software watchdog time-out. This occurs when the software watchdog counter reaches zero.
4	CR	If set, the source of reset is a checkstop. This occurs when the processor enters the checkstop state and the checkstop reset is enabled.
5	JTAG	If set, the source of reset is the JTAG module. This reset occurs only during production testing.
6:31	—	Reserved

5.8.2 Reset Flow

The reset flow can be divided into two flows: external reset request flow and the internal reset request flow.

5.8.2.1 External Reset Request Flow

Figure 5-31 is a flow diagram for external resets.

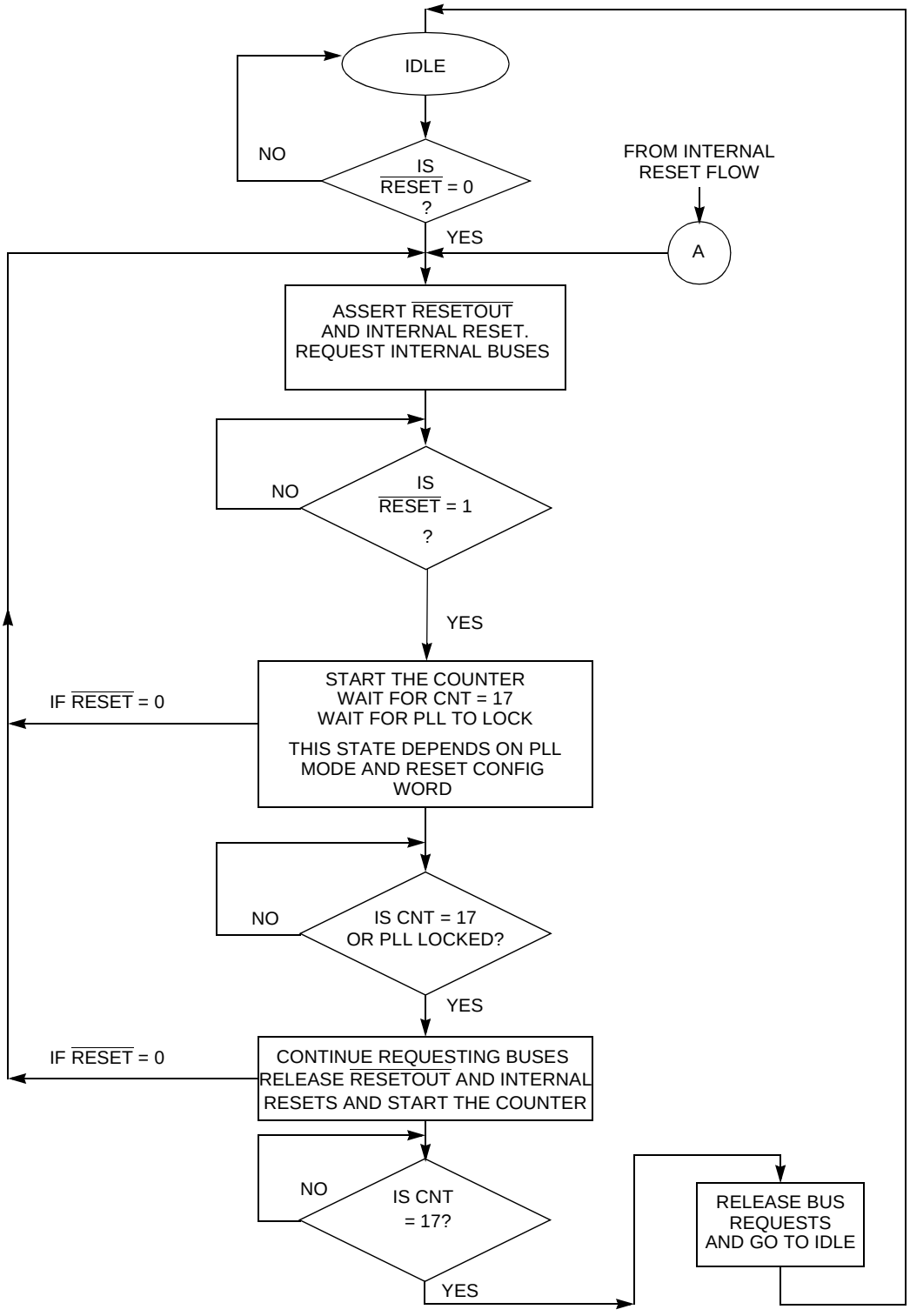


Figure 5-31 External Reset Request Flow

The external reset flow begins when the $\overline{\text{RESET}}$ pin is asserted (low). The external reset request has a synchronization phase during which it takes one of the two paths

(synchronous or asynchronous) before getting to the reset control logic. The external reset request follows the asynchronous path in the case of power-on reset or in case of loss of oscillator.

Under all remaining conditions the reset request goes through the synchronous path, in which the reset request is synchronized with the system clock. RESET must be asserted for at least two clock cycles to be recognized by the reset control block.

Once the reset request passes through the synchronization phase, the chip enters reset. The RESETOUT pin and the internal reset signal are driven while the chip is in reset. (Note that this internal reset signal is an output from the reset control block that is sent to the internal MCU modules. This signal is different from internal reset request, which are inputs to the reset control block.) Six clock cycles after RESET is negated, all mode select pins are sampled except for the VDDSN and MODCLK pins. These two pins are sampled at the rising edge of RESETOUT.

After the RESET pin is negated, RESETOUT is held for a minimum of 17 clock cycles. After the 17 clock cycles, the state of data bus configuration bit 19 and the phase-locked loop (PLL) mode determine when RESETOUT is released.

- If the PLL is operating in 1:1 mode or the data bus configuration bit 19 is cleared, RESETOUT is released when the PLL is locked.
- If data bus configuration bit 19 is set and the PLL is not operating in 1:1 mode, RESETOUT is released as soon as the 17 clock cycles have finished.

When the PLL is operating in 1:1 mode, the MCU waits until the PLL is locked before releasing RESETOUT, since the clock which is an input to the MCU may also be used as an input to other bus devices. In addition, if other bus devices use the MCU CLKOUT signal to feed a PLL, the user must ensure that the PLL is locked before RESETOUT is released. This is achieved by clearing data bus configuration bit 19 at reset.

While RESETOUT is being asserted, the SIU requests control of the I-bus and L-bus. The IMB2 interface requests control of the IMB2 bus. Internal reset is released when RESETOUT is released; however, the internal buses are not released until 16 clock cycles after RESETOUT is negated.

If an external reset is asserted any time during this process, this process begins again.

5.8.2.2 Internal Reset Request Flow

Figure 5-32 is a flow diagram for internal reset requests.

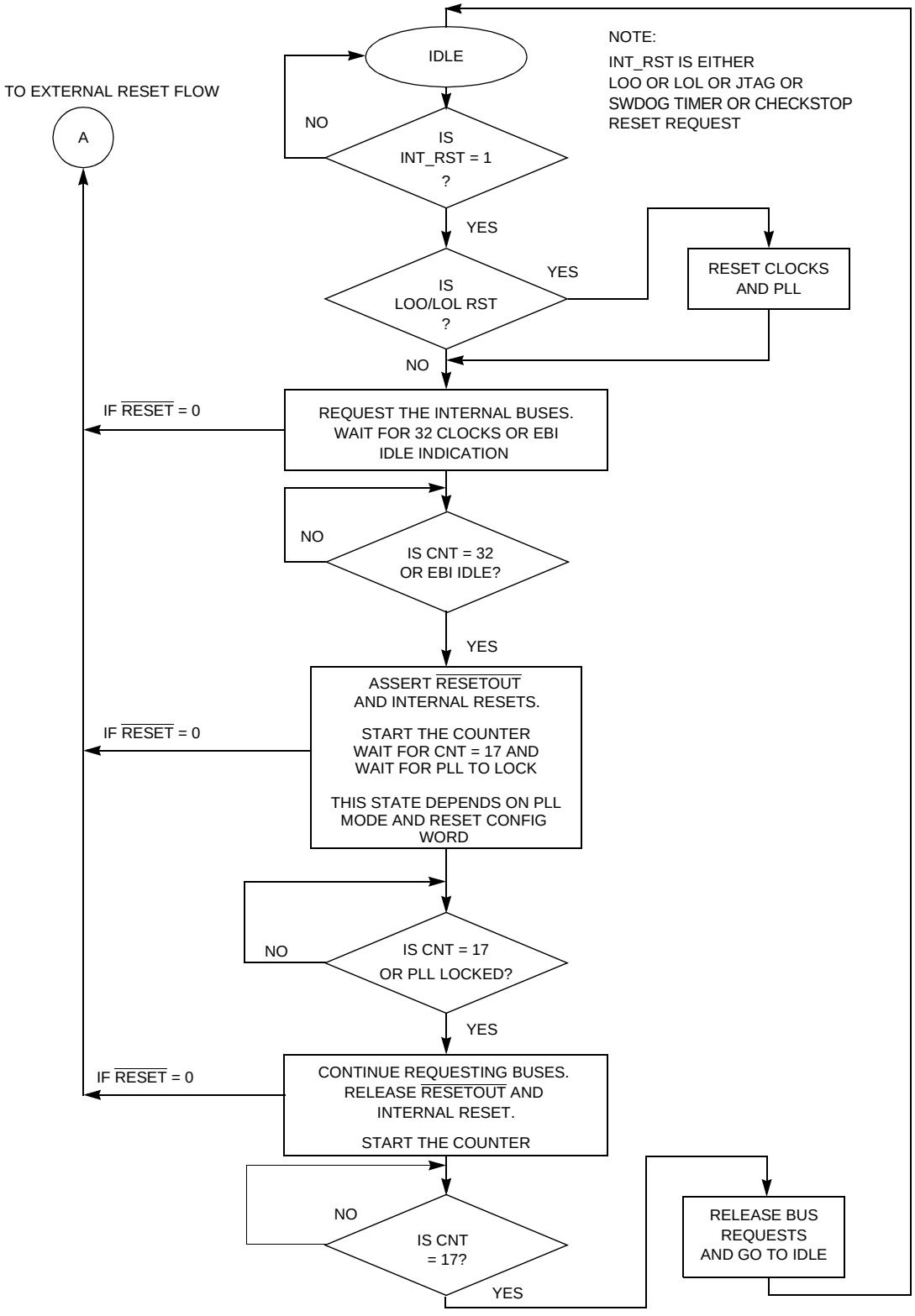


Figure 5-32 Internal Reset Request Flow

The SIU enters internal reset flow when an internal reset request is issued due to one of the following causes: loss of clock, loss of PLL lock, software watchdog time-out, entry into checkstop state, or assertion of a JTAG reset request. If the source of reset is either loss of oscillator or loss of clock, the SIU resets the clocks and the PLL immediately. For other reset sources, the SIU does not reset the clocks or the PLL.

When the internal reset request signal is asserted, the SIU attempts to complete the current transaction on the external bus before placing the chip (except clocks and PLL) in reset. The SIU requests the L-bus and I-bus and removes the qualified bus grant from the EBI to make sure that no new transaction is started.

The SIU waits for 32 clock cycles (after internal reset request is asserted) or for the EBI to indicate that the SIU is idle, whichever occurs first. Then the SIU asserts $\overline{\text{RESETOUT}}$ and internal reset. $\overline{\text{RESETOUT}}$ and internal reset will be driven out to put the chip into reset. Four clock cycles after the assertion of $\overline{\text{RESETOUT}}$, all mode select pins will be sampled except V_{DDSN}, DSCK and MODCLK pins which are sampled at the rising edge of $\overline{\text{RESETOUT}}$.

$\overline{\text{RESETOUT}}$ is held for a minimum of 17 clock cycles. After the 17 clock cycles, the state of data bus configuration bit 19 determines when $\overline{\text{RESETOUT}}$ is released.

- If the PLL is operating in 1:1 mode or the data bus configuration bit 19 is cleared, $\overline{\text{RESETOUT}}$ is released when the phase-locked loop (PLL) is locked.
- If data bus configuration bit 19 is set and the PLL is not operating in 1:1 mode, $\overline{\text{RESETOUT}}$ is released as soon as the 17 clock cycles have finished.

Internal reset is released when $\overline{\text{RESETOUT}}$ is released; however, the internal buses are not released until 17 clocks after $\overline{\text{RESETOUT}}$ is negated.

If an external reset is asserted any time during this process, the external reset flow begins.

5.8.2.3 Reset Behavior for Different Clock Modes

Table 5-47 summarizes the conditions under which internal reset is released for each clock mode.

Table 5-47 Reset Behavior for Different Clock Modes

Clock Mode	V_{DDSN}	MODCLK	Internal DATA19 = 1 at Reset	Internal DATA19 = 0 at Reset
Normal operation	1	1	Release internal reset 17 clocks after $\overline{\text{RESET}}$ is negated	Release internal reset when PLL is locked and 17 clocks after $\overline{\text{RESET}}$ is negated OR when time-out value in the time base register has expired (whichever occurs first)
1:1 mode	1	0	Release internal reset when PLL is locked and 17 clocks after $\overline{\text{RESET}}$ is negated	
SPLL bypass mode	0	1	Release internal reset 17 clocks after $\overline{\text{RESET}}$ is negated	
Special test mode	0	0	Release internal reset 17 clocks after $\overline{\text{RESET}}$ is negated	

5.8.3 Configuration During Reset

Many SIU pins can have more than one function. The logic state of certain mode-select pins during reset determines which functions are assigned to pins with multiple functions. These mode-select pins determine other aspects of operating configuration as well.

Basic operating configuration is determined by the DSDI and DSCK pins, as shown in **Table 5-48**.

Table 5-48 Pin Configuration During Reset

Pin During Reset	Function Affected
DSCK asserted (1)	Debug mode enabled
DSCK negated (0)	Debug mode disabled
DSDI asserted (1)	Data bus configuration mode
DSDI negated (0)	Internal default mode

The state of the DSDI pin is latched internally five clock cycles after $\overline{\text{RESETOUT}}$ is asserted. The state of the DSCK pin is latched every clock cycle while $\overline{\text{RESETOUT}}$ is asserted. The MCU is configured based on the values latched from these two pins. The user is responsible for ensuring a valid level on these pins five clock cycles after $\overline{\text{RESETOUT}}$ is asserted. If DSDI is asserted (causing data bus configuration mode to be entered), the user must also drive DATA[0:5], at a minimum.

For any reset source other than external reset, the external data pins are latched five clock cycles after internal reset control logic asserts $\overline{\text{RESETOUT}}$. For external resets, the data pins are latched five clock cycles after $\overline{\text{RESET}}$ is negated. The default reset configuration word is driven onto the internal buses until the external word is latched. If no external reset configuration word is latched, the default word continues to be driven on the internal buses.

This scheme allows users of the internal default mode to limit their required external configuration hardware to two pull-down resistors (DSDI and DSCK). It also allows many options to be configured with a single three-state octal buffer.

5.8.3.1 Data Bus Configuration Mode

If data bus configuration mode is selected (DSDI asserted), then the MCU is configured according to the values latched from the data bus pins.

NOTE

$\overline{\text{BG}}$ must be asserted in order for the reset configuration word latch to access the data bus.

The external data bus is divided into four groups:

- DSDI, DATA[0:5]
- DATA[6:13]
- DATA[14:21]

- DATA[22:31]

This grouping allows the user to use three-state octal buffers to only drive valid data on the pins for those reset configuration options that the user would want to change. The state of the last pin in each group (pins 5, 13, and 21) determines whether the next set of configuration options use the internal default values or are configured from the external data bus. The user is required to drive to a valid level all the pins in any of the groups that are to be changed. The functions selected by these pins are shown in **Table 5-49**.

5.8.3.2 Internal Default Mode

If DSDI is held low during reset, internal default mode is selected. The internal default mode allows MCUs with on-board non-volatile memory modules (such as flash EEPROM) to provide a pin configuration word on the instruction or load/store data bus during reset. For MCUs without such a memory module, such as the MPC509, the SIU provides a mask-programmed default value.

5.8.3.3 Data Bus Reset Configuration Word

In either reset configuration mode (data bus configuration mode or internal default mode), the configuration is accomplished within the MCU by driving a configuration word on the internal data bus before the internal $\overline{\text{RESET}}$ signal is negated. At the negation of internal $\overline{\text{RESET}}$, those functions that are configured at reset latch their configuration values from the assigned bits of the internal data bus. The format of the data bus reset configuration word is the same regardless of which configuration mode is selected, except that data bus bits 5, 13, and 21 have no meaning in internal default mode. **Table 5-49** describes the configuration options.

Table 5-49 Data Bus Reset Configuration Word

Data Bus Bit	Configuration Function Affected	Effect of Mode Select = 1 During Reset	Effect of Mode Select = 0 During Reset	Internal Default Mode	
				3 V I/O[1]	TTL I/O[2]
0	Address Bus	Minimum Bus Mode ADDR[0:11]/$\overline{CS}$[0:11] configured as chip selects	Maximum Bus Mode ADDR[0:11]/$\overline{CS}$[0:11] configured as address pins	1	1
1	Vector Table Location (IP Bit)	Vector Table 0xFFF0 0000	Vector Table 0x0000 0000	0	1
2	Burst Type/Indication	Type 2 ($\overline{LAST}$ Timing)	Type 1 ($\overline{BDIP}$ Timing)	0	0
3	Interface Type for $\overline{CSBOOT}$	ITYPE = 001 Asynchronous (Time to Hi-Z = 2 Clk)	ITYPE = 1000 Synchronous Burst	1	1
4	$\overline{CSBOOT}$ Port Size	32-Bit	16-Bit	1	0
5	Reset Configuration Source For DATA[6:13]	Latch configuration from external pins	Latch configuration from internal defaults	0	0
6:8	$\overline{TA}$ Delay For $\overline{CSBOOT}$	$\overline{TA}$ Delay Encoding 000 001 010 011 100 101 110 111	Number of Wait States 0 1 2 3 4 5 6 7	010	111
9:10	IMEMBASE[0:1]	IMEMBASE 00 01 10 11	I-Mem Block Placement Start Addr: 0x0000 0000 End Addr: 0x000F FFFF Start Addr: 0xFFF0 0000 End Addr: 0xFFFF FFFF Note: MPC509 does not contain I-Mem	01	10
11:12	LMEMBASE[0:1]	LMEMBASE 00 01 10 11	L-Mem (SRAM) Block Placement Start address: 0x0000 0000 End address: 0x000F FFFF Start address: 0xFFF0 0000 End address: 0xFFFF FFFF	11	11
13	Reset configuration source for DATA[14:21]	Latch configuration from external pins	Latch configuration from internal defaults	0	0
14	CT[0:3], AT[0:1], $\overline{TS}$	CT[0:3], AT[0:1], $\overline{TS}$	PJ[1:7]	1	1
15	$\overline{WR}$, $\overline{BDIP}$	$\overline{WR}$, $\overline{BDIP}$	PK[0:1]	1	1
16	PLLL/DSDO, VF[0:2], VFLS[0:1], WP[1:5]	DSDO, Pipe Tracking, Watchpoints	PK[2:7], PL[2:7]	1	1
17	$\overline{BURST}$, $\overline{TEA}$, $\overline{AACK}$, $\overline{TA}$, $\overline{BE[0:3]}$	Handshake Pins	PORTI[0:7]	1	1
18	$\overline{CR}$, $\overline{BI}$, $\overline{BR}$, $\overline{BB}$, $\overline{BG}$, $\overline{ARETRY}$	Bus Arbitration Pins	PM[2:7]	1	1
19	Release reset when PLL locked	Refer to **Table 5-47**	Refer to **Table 5-47**	0	1
20	Reserved			0	0

Table 5-49 Data Bus Reset Configuration Word (Continued)

Data Bus Bit	Configuration Function Affected	Effect of Mode Select = 1 During Reset	Effect of Mode Select = 0 During Reset	Internal Default Mode	
				3 V I/O[1]	TTL I/O[2]
21	Reset configuration source For DATA[22:31]	Latch configuration from external pins	Latch configuration from internal defaults	0	0
22	Reserved			0	0
23	Reserved			0	0
24	LEN	L-bus memory modules are enabled.	L-bus memory modules are disabled and emulated externally	1	1
25	PRUMODE	Forces accesses to ports A, B, I, J, K, and L to go external	No effect	0	0
26	ADDR[12:15]	ADDR[12:15]	PB[4:7]	1	1
27	Reserved			0	0
28	Reserved			0	0
29	Reserved			0	0
30	Test Slave Mode Enable	Test Slave Mode Disabled	Test Slave Mode Enabled	1	1
31	Test Transparent Mode Enable	Test Transparent Mode Disabled	Test Transparent Mode Enabled	1	1

NOTES:
1. 3 V only I/O structure. The part number is MPC509L (CFT33).
2. TTL compatible (5 V friendly input) I/O structure. The part number is MPC509L3 (CFT33).

5.8.4 Power-On Reset

Power-on reset occurs when the VDDKAP1 pin is high and V_{DD} makes a transition from zero to one. The SIU does not have a power-on reset circuit. This function must be provided externally.

NOTE

The ADDR[0:11]/$\overline{\text{CS}}$[0:11] pins contain unknown values during the first two clocks of power-on reset. The user must ensure that external EEPROM and standby memory interface logic do not allow inadvertent writes during this time.

5.9 General-Purpose I/O

Many of the pins associated with the SIU can be used for more than one function. The primary function of these pins is to provide an external bus interface. When not used for their primary function, many of these pins can be used as digital I/O pins.

SIU digital I/O pins are grouped into eight-bit ports. The following registers are associated with each I/O port. (Output-only ports do not have a data direction register.)

- Pin assignment register — allows the user to configure a pin for its primary function or digital I/O.
- Data direction register — configures individual pins as input or output pins.
- Data register — monitors or controls the state of its pins, depending on the state

of the data direction register for that pin.

If a pin is not configured as an I/O port pin in the pin assignment register, the data direction and data registers have no effect on the pin.

Ports A through L can be used with a port replacement unit (PRU). These ports provide three-clock-cycle access. If PRU mode is enabled at reset, access to these registers is disabled, and an external bus cycle is initiated. Other (non-PRU) ports provide two-clock-cycle access.

In addition to the SIU ports described in this section, port Q in the peripherals controller unit provides edge- or level-sensitive I/O. Refer to **6.5 Port Q** for information on port Q.

Table 5-50 is an address map of the SIU port registers.

Table 5-50 SIU Port Registers Address Map

Access	Address	Register
S	0x8007 FC60	Port M Data Direction (DDRM)
S	0x8007 FC64	Port M Pin Assignment (PMPAR)
S/U	0x8007 FC68	Port M Data (PORTM)
—	0x8007 FC6C – 0x8007 FC80	Reserved
S	0x8007 FC84	Port A, B Pin Assignment (PAPAR, PBPAR)
S/U	0x8007 FC88	Port A, B Data (PORTA, PORTB)
—	0x8007 FC8C – 0x8007 FC94	Reserved
S	0x8007 FC98	Port I, J, K, L Data Direction (DDRI, DDRJ, DDRK, DDRL)
S	0x8007 FC9C	Port I, J, K, L Pin Assignment (PIPAR, PJPAR, PKPAR, PLPAR)
S/U	0x8007 FCA0	Port I, J, K, L Data (PORTI, PORTJ, PORTK, PORTL)
—	0x8007 FCA4 – 0x8007 FCFF	Reserved

5.9.1 Port Timing

Ports A through L can be used with a port replacement unit (PRU). These ports provide three-clock-cycle access. If PRU mode is enabled at reset, access to these registers is disabled, and an external bus cycle is initiated. Other (non-PRU) ports provide two-clock-cycle access. Input port pins are sampled synchronously.

After a pin assignment or data direction register is modified, the change may require an additional clock cycle to take effect at the pin.

Note that the timing of output port pins does not match the timing of the corresponding bus control pins.

5.9.2 Port M

PORTM — Port M Data Register **0x8007 FC68**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	PM3	PM4	PM5	PM6	PM7	RESERVED							
RESET:															
0	0	0	U	U	U	U	U	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U = Unaffected by reset

Writes to PORTM are stored in internal data latches. If any bit of the port is configured as an output, the value latched for that bit is driven onto the pin. A read of PORTM returns the value at the pin only if the pin is configured as a discrete input. Otherwise, the value read will be the value stored in the internal data latch. PORTM can be read or written at any time. This register is unaffected by reset.

DDRM — Port M Data Direction Register **0x8007 FC60**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	DDM3	DDM4	DDM5	DDM6	DDM7	RESERVED							
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The bits in this register control the direction of the port M pin drivers when the pins are configured as I/O pins. Setting a bit in this register to one configures the corresponding pin as an output; clearing the bit configures the pin as an input.

PMPAR — Port M Pin Assignment Register **0x8007 FC64**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	PMPA 2	PMPA 3	PMPA 4	PMPA 5	PMPA 6	PMPA 7	RESERVED							
RESET:															
0	0	*	*	*	*	*	*	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Reset setting depends on the value of the configuration word at reset.

The bits in this register control the function of the associated pins. Setting a bit in this register to one configures the corresponding pin as a bus control signal; clearing a bit configures the pin as an I/O pin (or as the $\overline{DS}$ signal, in the case of PMPA2).

Table 5-51 Port M Pin Assignments

PMPAR Bit	Port M Signal	Bus Control Signal
PMPA2	$\overline{DS}$	$\overline{CR}$
PMPA3	PM3	$\overline{BI}$
PMPA4	PM4	$\overline{BR}$
PMPA5	PM5	$\overline{BB}$
PMPA6	PM6	$\overline{BG}$
PMPA7	PM7	$\overline{ARETRY}$

5.9.3 Ports A and B

Ports A and B are 8-bit output ports. Associated with each port is a data register and a pin assignment register; data direction registers are not needed.

PORTA, PORTB — Port A, B Data Registers **0x8007 FC88**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PA0	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PB0	PB1	PB2	PB3	PB4	PB5	PB6	PB7
RESET:															
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U = Unaffected by reset

When a port A or port B pin is configured as a general-purpose output, the value in the port A or port B data register is driven onto the pin. PORTA and PORTB are unaffected by reset.

PAPAR, PBPAR — Port A, B Pin Assignment Register **0x8007 FC84**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PAPA 0	PAPA 1	PAPA 2	PAPA 3	PAPA 4	PAPA 5	PAPA 6	PAPA 7	PBPA 0	PBPA 1	PBPA 2	PBPA 3	PBPA 4	PBPA 5	PBPA 6	PBPA 7
RESET:															
1	1	1	1	1	1	1	1	1	1	1	1	*	*	*	*

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Reset setting depends on the value of the configuration word at reset.

Each bit in this register controls the function of the associated pin, provided the pin is configured for non-chip-select function in the corresponding chip-select options register. Setting a bit in the PAPAR or PBPAR configures the corresponding pin as an address bus pin; clearing the bit configures the pin as an I/O pin.

Table 5-52 Port A Pin Assignments

PMPAR Bit	Port A Signal	Bus Control Signal
PAPA0	PA0	ADDR0
PAPA1	PA1	ADDR1
PAPA2	PA2	ADDR2
PAPA3	PA3	ADDR3
PAPA4	PA4	ADDR4
PAPA5	PA5	ADDR5
PAPA6	PA6	ADDR6
PAPA7	PA7	ADDR7

Table 5-53 Port B Pin Assignments

PMPAR Bit	Port B Signal	Bus Control Signal
PBPA0	PB0	ADDR8
PBPA1	PB1	ADDR9
PBPA2	PB2	ADDR10
PBPA3	PB3	ADDR11
PBPA4	PB4	ADDR12
PBPA5	PB5	ADDR13
PBPA6	PB6	ADDR14
PBPA7	PB7	ADDR15

5.9.4 Ports I, J, K, and L

PORTI, PORTJ, PORTK, PORTL — Port I, J, K, L Data Registers **0x8007 FCA0**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PI0	PI1	PI2	PI3	PI4	PI5	PI6	PI7	0	PJ1	PJ2	PJ3	PJ4	PJ5	PJ6	PJ7
RESET:															
U	U	U	U	U	U	U	U	0	U	U	U	U	U	U	U

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
PK0	PK1	PK2	PK3	PK4	PK5	PK6	PK7	0	0	PL2	PL3	PL4	PL5	PL6	PL7
RESET:															
U	U	U	U	U	U	U	U	0	0	U	U	U	U	U	U

U = Unaffected by reset

Writes to port I, J, K, and L data registers are stored in internal data latches. If any pin in one of these ports is configured as an output, the value latched for the corresponding data register bit is driven onto the pin. A read of one of these data registers returns the value at the pin only if the pin is configured as a discrete input. Otherwise, the value read is the value stored in the internal data latch. Port I, J, K, and L data registers can be read at any time. These registers are unaffected by reset.

DDRI, DDRJ, DDRK, DDRL — Port I, J, K, L Data Direction Registers **0x8007 FC98**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DDI0	DDI1	DDI2	DDI3	DDI4	DDI5	DDI6	DDI7	0	DDJ1	DDJ2	DDJ3	DDJ4	DDJ5	DDJ6	DDJ7
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
DDK0	DDK1	DDK2	DDK3	DDK4	DDK5	DDK6	DDK7	0	0	DDL2	DDL3	DDL4	DDL5	DDL6	DDL7
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The bits in these registers control the direction of the associated pin drivers when the pins are configured as I/O pins. Setting a bit in these registers configures the corresponding pin as an output; clearing the bit configures the pin as an input.

PIPAR, PJPAR,
PKPAR, PLPAR — Port I, J, K, L Pin Assignment Registers **0x8007 FC9C**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PIPA0	PIPA1	PIPA2	PIPA3	PIPA4	PIPA5	PIPA6	PIPA7	0	PJPA1	PJPA2	PJPA3	PJPA4	PJPA5	PJPA6	PJPA7
RESET:															
*	*	*	*	*	*	*	*	0	*	*	*	*	*	*	*

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
PKPA 0	PKPA 1	PKPA 2	PKPA 3	PKPA 4	PKPA 5	PKPA 6	PKPA 7	0	0	PLPA2	PLPA3	PLPA4	PLPA5	PLPA6	PLPA7
RESET:															
*	*	*	*	*	*	*	*	0	0	*	*	*	*	*	*

* Reset setting depends on the value of the configuration word at reset.

The bits in these registers control the function of the associated pins. Setting a bit configures the corresponding pin as a bus control signal; clearing the bit configures the pin as an I/O pin.

Table 5-54 Port I Pin Assignments

PIPAR Bit	Port I Signal	Bus Control Signal
PIPA0	PI0	$\overline{\text{BURST}}$
PIPA1	PI1	$\overline{\text{TEA}}$
PIPA2	PI2	$\overline{\text{AACK}}$
PIPA3	PI3	$\overline{\text{TA}}$
PIPA4	PI4	$\overline{\text{BE0}}$
PIPA5	PI5	$\overline{\text{BE1}}$
PIPA6	PI6	$\overline{\text{BE2}}$
PIPA7	PI7	$\overline{\text{BE3}}$

Table 5-55 Port J Pin Assignments

PJPAR Bit	Port J Signal	Bus Control Signal
PJPA1	PJ1	AT0
PJPA2	PJ2	AT1
PJPA3	PJ3	$\overline{\text{TS}}$
PJPA4	PJ4	CT0
PJPA5	PJ5	CT1
PJPA6	PJ6	CT2
PJPA7	PJ7	CT3

Table 5-56 Port K Pin Assignments

PKPAR Bit	Port K Signal	Bus Control Signal
PKPA0	PK0	$\overline{\text{BDIP}}$
PKPA1	PK1	$\overline{\text{WR}}$
PKPA2	PK2	PLLL/DSDO
PKPA3	PK3	VF0
PKPA4	PK4	VF1
PKPA5	PK5	VF2
PKPA6	PK6	VFLS0
PKPA7	PK7	VFLS1

Table 5-57 Port L Pin Assignments

PLPAR Bit	Port L Signal	Bus Control Signal
PLPA2	PL2	WP0
PLPA3	PL3	WP1
PLPA4	PL4	WP2
PLPA5	PL5	WP3
PLPA6	PL6	WP4
PLPA7	PL7	WP5

5.9.5 Port Replacement Unit (PRU) Mode

The entire external bus interface must be supported in order to build an emulator for an MCU. The SIU contains support for external port replacement logic which can be used to faithfully replicate on-chip ports externally. This PRU mode allows system development of a single-chip application in expanded mode. Access (including access time) to the port replacement logic can be made transparent to the application software.

In PRU mode, all data, data direction, and pin assignment registers for ports A, B, I, J, K, and L are mapped externally. The SIU does not respond to these accesses, allowing external logic, such as a PRU, to respond.

PRU mode is invoked by pulling DATA25 high during reset. Other pins should be configured as bus control pins.

SECTION 6
PERIPHERAL CONTROL UNIT

The peripheral control unit (PCU) consists of the following submodules:

- Software watchdog — provides system protection.
- Interrupt controller — controls the interrupts that external peripherals and internal modules send to the CPU.
- Port Q — provides for digital I/O on pins that are not being used as interrupt inputs.
- Test submodule — allows factory testing of the MCU.
- L-bus/IMB2 interface (LIMB) — provides an interface between the load/store bus and the second generation intermodule bus (IMB2). The IMB2 connects on-chip peripherals to the processor via the LIMB.

6.1 PCU Block Diagram

Figure 6-1 shows a block diagram of the PCU.

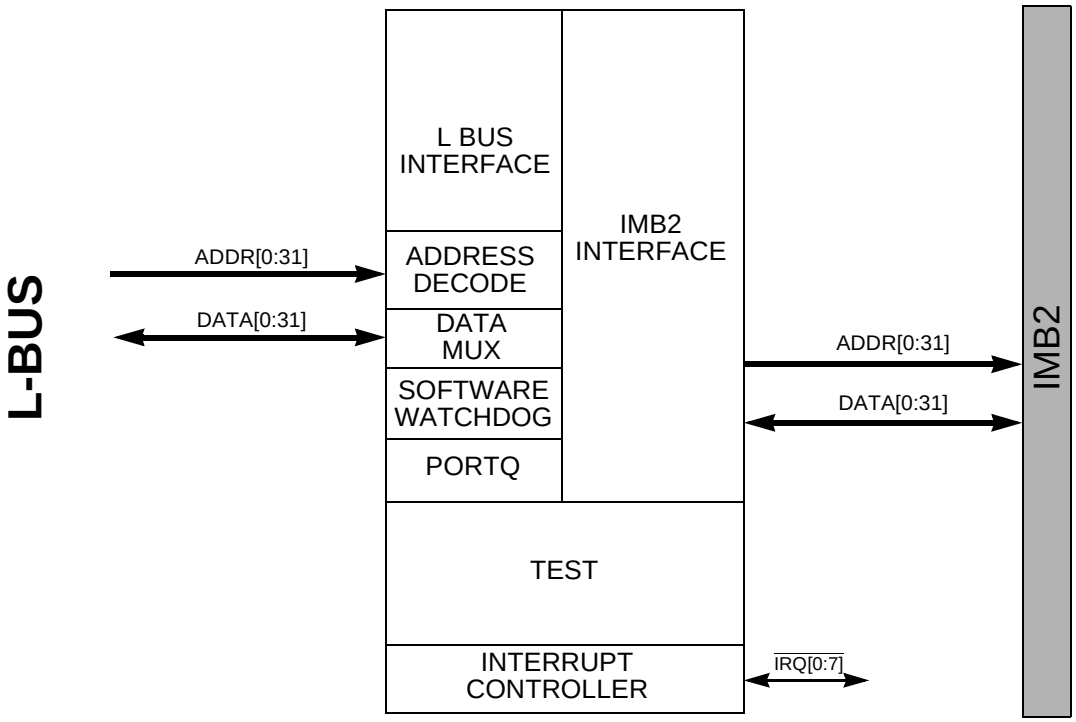


Figure 6-1 Peripherals Control Unit Block Diagram

6.2 PCU Address Map

Table 6-1 shows the address map for the PCU. An entry of “S” in the Access column indicates that the register is accessible in supervisor mode only. “S/U” indicates that the register can be programmed to the desired privilege level. “Test” indicates that the register is accessible in test mode only.

Table 6-1 PCU Address Map

Access	Address	Register	
S	0x8007 EF80	Peripheral Control Unit Module Configuration Register (PCUMCR)	
—	0x8007 EF84 – 0x8007 EF8C	Reserved	
Test	0x8007 EF90	Test Control Register (TSTMSRA)	Test Control Register (TSTMSRB)
Test	0x8007 EF94	Test Control Register (TSTCNTRAB)	Test Control Register (TSTREPS)
Test	0x8007 EF98	Test Control Register (TSTCREG1)	Test Control Register (TSTCREG2)
Test	0x8007 EF9C	Test Control Register (TSTDREG)	Reserved
S	0x8007 EFA0	Pending Interrupt Request Register (IRQPEND)	
S	0x8007 EFA4	Enabled Active Interrupt Request Register (IRQAND)	
S	0x8007 EFA8	Interrupt Enable Register (IRQENABLE)	
S	0x8007 EFAC	PIT/Port Q Interrupt Level Register (PITQIL)	
—	0x8007 EFB0 – 0x8007 EFBC	Reserved	
S	0x8007 EFC0	Software Service Register (SWSR)	Reserved
S	0x8007 EFC4	Software Watchdog Control Field/Timing Count (SWCR/SWTC)	
S/U	0x8007 EFC8	Software Watchdog Register	
—	0x8007 EFCC	Reserved	
S/U	0x8007 EFD0	Port Q Edge Detect/Data (PQEDGDAT)	Reserved
S	0x8007 EFD4	Port Q Pin Assignment Register (PQPAR)	
—	0x8007 EFD8 – 0x8007 EFFC	Reserved	

CAUTION

Avoid writing to test location 0x8007 EF98. Setting the high-order bit in this reserved register causes the MCU to enter test mode.

6.3 Module Configuration

The peripheral control unit module configuration register (PCUMCR) contains fields for stopping the system clock to IMB2 modules, assigning certain PCU registers to either supervisor or unrestricted memory space, and assigning the number of interrupt request levels available to IMB2 peripherals.

PCUMCR — Peripheral Control Unit Module Configuration Register **0x8007 EF80**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
STOP	IRQMUX		RESERVED					SUPV		RESERVED					
RESET:															
0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6-2 PCUMCR Bit Settings

Bit(s)	Name	Description
0	STOP	Stop system clock to peripherals controller 0 = Enable system clock to IMB2 modules 1 = Disable system clock to IMB2 modules
1:2	IRQMUX	Interrupt request multiplexer control 00 = Disable multiplexing scheme (eight possible interrupt sources) 01 = 2-to-1 multiplexing (16 possible interrupt sources) 10 = 3-to-1 multiplexing (24 possible interrupt sources) 11 = 4-to-1 multiplexing (32 possible interrupt sources) Refer to **6.5.2.3 Interrupt Request Multiplexing** for details.
3:7	—	Reserved
8:9	SUPV	Supervisor access for PCU registers 00 = Supervisor/unrestricted registers respond to accesses in supervisor or user data space. 01 = Supervisor/unrestricted registers respond to accesses in supervisor space only. 10 = Supervisor/unrestricted registers respond to read accesses in either data space, but write accesses can only be performed in supervisor data space. 11 = Undefined
10:31	—	Reserved

6.4 Software Watchdog

The software watchdog monitors the system software interfaces and requires the software to take periodic action in order to ensure that the program is executing properly. To protect against software error, the following service must be executed on a regular basis:

1. Write 0x556C to the SWSR
2. Write 0xAA39 to the SWSR

This sequence clears the watchdog timer, and the timing process begins again. If this periodic servicing does not occur, the software watchdog issues a reset.

Any number of instructions may occur between the two writes to the SWSR. If any value other than 0x556C or 0xAA39 is written to the SWSR, however, the entire sequence must start over.

6.4.1 Software Watchdog Service Register

A write of 0x556C followed by a write of 0xAA39 to the software watchdog service register (SWSR) causes the software watchdog register to be reloaded with the value in the software watchdog timing count (SWTC) field of the SWCR.

This register can be written at any time within the time-out period. A write of any value other than those shown above resets the servicing sequence, requiring both values to be written to the SWSR before the value in the SWTC field is reloaded into the SWSR.

Reads of the SWSR return zero.

SWSR — Software Watchdog Service Register **0x8007 EFC0**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
SWSR																RESERVED															
RESET:																															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

6.4.2 Software Watchdog Control Register/Timing Count

The software watchdog control register/timing count consists of the software watchdog enable (SWE) and software watchdog lock (SWLK) bits and the timing count field for the software watchdog. The software watchdog timing count (SWTC) field contains the 24-bit value that is loaded into the SWSR upon completion of the software watchdog service sequence.

When the SWLK bit is cleared, this register can be written. Once the lock bit is set, further writes to this register have no effect. (In debug mode, however, the lock bit can be cleared by software.) The register can be read at any time.

SWCR/SWTC — Software Watchdog Control Field/Timing Count **0x8007 EFC4**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	0	SWE	SWLK	SWTC							
RESET:															
0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
SWTC															
RESET:															
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 6-3 SWCR/SWTC Bit Settings

Bit(s)	Name	Description
0:5	—	Reserved
6	SWE	Software watchdog enable 0 = Disable watchdog counter 1 = Enable watchdog counter
7	SWLK	Software watchdog lock 0 = Enable changes to SWLK, SWE, SWTC 1 = Ignore writes to SWLK, SWE, SWTC
8:31	SWTC	Software watchdog timing count. This 24-bit register contains the count for the software watchdog timer, which counts at system clock frequency. If this register is loaded with zero, the maximum time-out is programmed.

6.4.3 Software Watchdog Register

The software watchdog register (SWR) is a read-only register that shows the current value of the software watchdog down counter. Writes to this register have no effect.

SWR — Software Watchdog Register **0x8007 EFC8**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED								SWR																							
RESET:																															
X	X	X	X	X	X	X	X	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

6.5 Interrupt Controller

Interrupts provide a mechanism for asynchronous, real-time communication between I/O devices and the CPU. The MPC509 interrupt controller joins the simple interrupt structure of the CPU with the complex structure of interrupt sources in the system. The CPU has a single maskable external interrupt. A complete MPC509-based system can have multiple interrupting modules, each with multiple interrupt sources.

The interrupt controller consolidates all the interrupt sources into a single interrupt signal to the processor. Interrupt sources include the periodic interrupt timer, external interrupt pins, and any IMB2 peripherals.

External interrupt input pins are grouped into a general-purpose port (port Q). When not used as interrupt inputs, any of these pins can be used for digital input or output. Port Q operation is described in 6.6 Port Q.

6.5.1 Interrupt Controller Operation

The following control and status registers associated with the interrupt controller indicate which of 32 possible interrupt levels are pending and control which interrupt sources are passed on to the CPU:

- The pending interrupt request register (IRQPEND) contains a status bit for each of the 32 interrupt levels.
- The interrupt enable register (IRQENABLE) contains an enable bit for each of the

32 interrupt levels.

- The interrupt request levels register (PITQIL) determines the interrupt request level assigned to each interrupt source.

If a bit in the IRQPEND register is asserted (indicating that an interrupt request at the associated level is pending) and the corresponding bit in the IRQENABLE register is asserted, then the interrupt request line to the CPU will be asserted. These registers are described in greater detail in 6.5.3 Interrupt Controller Registers.

Figure 6-2 provides an overview of MPC509 interrupt management.

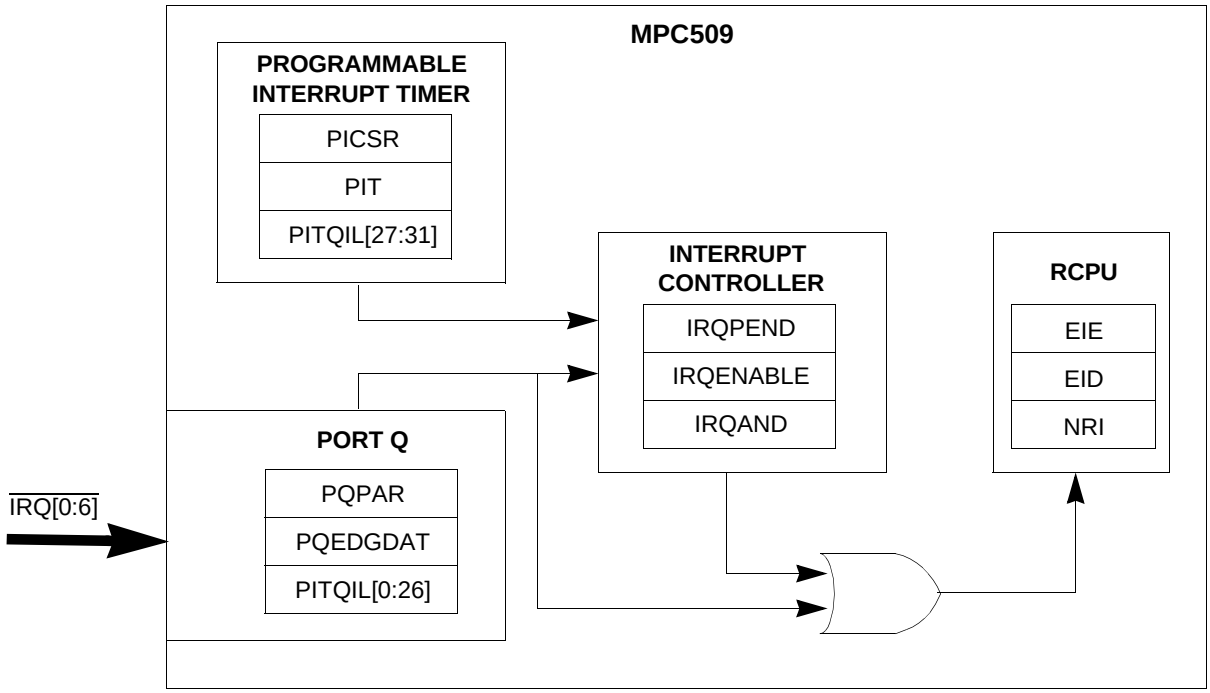


Figure 6-2 Interrupt Structure Block Diagram

The interrupt controller does not enforce a priority scheme. All interrupt priority is determined by the software. In addition, the interrupt controller does not automatically update the interrupt mask upon entering or leaving interrupt processing. Any updates to the interrupt mask are the responsibility of software. In this way, the system is not limited to a particular interrupt priority updating scheme.

In addition to the interrupt controller on the MCU, external peripheral chips in an MPC509-based system may contain their own interrupt controllers. Each interrupt input from an external peripheral chip to the MCU can be routed through the PCU interrupt controller or can be routed directly to the CPU $\overline{\text{IRQ}}$ input. This allows the system interrupts to be structured in a cascade, where an interrupt controller on an external chip is read only if a certain interrupt on the MCU is serviced, or in parallel, where all

interrupt controllers in the system are read and combined before it is determined which interrupt in the system needs servicing.

6.5.2 Interrupt Sources

Sources of interrupt requests to the interrupt controller include the periodic interrupt timer (PIT), two L-bus interrupt request sources, and the $\overline{\text{IRQ}}$[0:6] interrupt request pins. The request levels of PIT interrupts, IMB2 interrupts, and external $\overline{\text{IRQ}}$[0:2] interrupts are assigned by programming the PITQIL register. The request levels of $\overline{\text{IRQ}}$[3:6] external interrupts are assigned fixed values, as explained below.

CAUTION

Be sure the EE (external interrupt enable) bit in the MSR is cleared before changing the masks of any on- or off-chip interrupt sources or before negating any interrupt sources. (On-chip interrupt masks are the IRQENABLE register and the PIE bit in the PICSR.)

6.5.2.1 External Interrupt Requests

The levels of the $\overline{\text{IRQ}}$[0:2] interrupt request pins are assigned by programming the PITQIL. The remaining interrupt request pins have fixed values. $\overline{\text{IRQ3}}$ always generates a level 6 interrupt request; $\overline{\text{IRQ4}}$ generates a level 8 interrupt request; $\overline{\text{IRQ5}}$ generates a level 10 interrupt request; and $\overline{\text{IRQ6}}$ always generates a level 12 interrupt request.

6.5.2.2 Periodic Interrupt Timer Interrupts

The periodic interrupt timer (PIT) is a 16-bit counter that generates an interrupt whenever it counts down to zero, provided PIT interrupts are enabled. The PITIRQL (PIT interrupt request level) field in the PITQIL register assigns the interrupt request level for PIT interrupts. Refer to 5.7.3 Periodic Interrupt Timer (PIT) for details of PIT operation.

6.5.2.3 Interrupt Request Multiplexing

The IMB2 has ten lines for interrupt support: eight interrupt request lines ($\overline{\text{IRQ}}$[0:7]) from the interrupting modules and two multiplexer control inputs (ILBS[0:1]). This scheme enables the peripheral control unit to transfer up to 32 levels of interrupt requests to the interrupt controller.

When the four-to-one multiplexing scheme is used, the IMB2 $\overline{\text{IRQ}}$ lines update eight of the 32 bits of the IRQPEND register during each clock cycle. A maximum latency of four clock cycles and an average latency of two clock cycles result before the interrupt request can reach the interrupt controller.

Figure 6-3 illustrates the timing for the four-to-one multiplexing scheme.

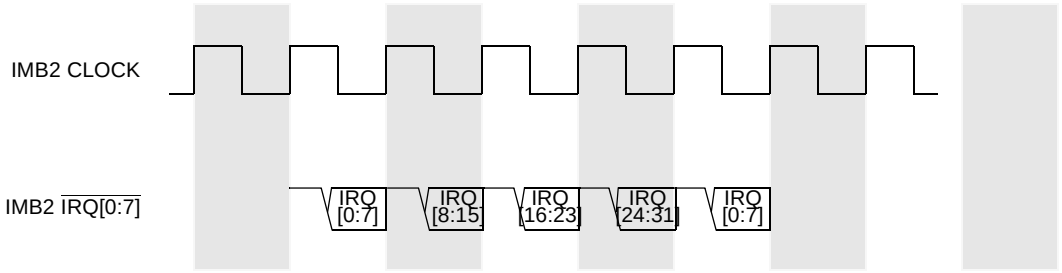


Figure 6-3 Time-Multiplexing Protocol For IRQ Pins

The IRQMUX field in the PCU module configuration register (PCUMCR) selects the type of multiplexing the interrupt controller performs. Refer to **Table 6-4**.

Table 6-4 IMB2 Interrupt Multiplexing

IRQMUX[0:1]	Available IRQ Levels	Type of Multiplexing	Maximum Latency
00	IRQ[0:7]	None	One clock cycle
01	IRQ[0:15]	Two to one	Two clock cycles
10	IRQ[0:23]	Three to one	Three clock cycles
11	IRQ[0:31]	Four to one	Four clock cycles

Time multiplexing is disabled during reset, but the reset default value enables time multiplexing as soon as reset is released.

6.5.3 Interrupt Controller Registers

Control and status registers associated with the interrupt controller indicate which of 32 possible interrupt levels are pending and control which interrupt sources are passed on to the CPU. **Table 6-5** lists these registers.

Table 6-5 Interrupt Controller Registers

Register	Description
Pending Interrupt Request Register (IRQPEND)	Contains a status bit for each of the 32 interrupt levels. Each bit of IRQPEND is a read-only status bit that reflects the current state of the corresponding interrupt signal.
Interrupt Enable Register (IRQENABLE)	Contains an enable bit for each of the 32 interrupt levels.
Enabled Active Interrupt Requests Register (IRQAND)	Logical AND of the IRQPEND and IRQENABLE registers. This register reflects which levels are actually causing the IRQ input to the CPU to be asserted.
Interrupt Request Levels Register (PITQIL)	Contains four 5-bit fields that determine the interrupt request levels of the PIT and the IRQ[0:2] pins.

6.5.3.1 Pending Interrupt Request Register

The pending interrupt request register (IRQPEND) is a read-only status register that reflects the state of the 32 interrupt levels.

IRQPEND — Pending Interrupt Request Register **0x8007 EFA0**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
L16	L17	L18	L19	L20	L21	L22	L23	L24	L25	L26	L27	L28	L29	L30	L31
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

6.5.3.2 Enabled Active Interrupt Requests Register

The enabled active interrupt requests register (IRQAND) is a read-only status register that is defined by the following equation:

$$IRQAND = IRQPEND \ \& \ IRQENABLE$$

where & is a bitwise operation.

IRQAND — Enabled Active Interrupt Requests Register **0x8007 EFA4**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
L16	L17	L18	L19	L20	L21	L22	L23	L24	L25	L26	L27	L28	L29	L30	L31
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

6.5.3.3 Interrupt Enable Register

The interrupt enable register (IRQENABLE) is a read/write register. The bits in this register are affected only by writes from the CPU (or other bus master) and by reset.

CAUTION

Be sure the EE (external interrupt enable) bit in the MSR is cleared before changing any masks in this register.

IRQENABLE — Interrupt Enable Register **0x8007 EFA8**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
L16	L17	L18	L19	L20	L21	L22	L23	L24	L25	L26	L27	L28	L29	L30	L31
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

6.5.3.4 PIT/Port Q Interrupt Levels Register

The PIT/port Q interrupt levels register (PITQIL) contains four 5-bit fields for programming the interrupt request level of the periodic interrupt timer (PIT) and the $\overline{\text{IRQ}}$[0:2] interrupt request pins. Refer to 6.5.2 Interrupt Sources for more information.

PITQIL — PIT/Port Q Interrupt Levels Register **0x8007 EFAC**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	IRQ0L					IRQ1L					IRQ2L				
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED											PITIRQL				
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6-6 PITQIL Bit Settings

Bit(s)	Name	Description
0	—	Reserved
1:5	IRQ0L	Interrupt request level for the $\overline{\text{IRQ0}}$ pin
6:10	IRQ1L	Interrupt request level for the $\overline{\text{IRQ1}}$ pin
11:15	IRQ2L	Interrupt request level for the $\overline{\text{IRQ2}}$ pin
16:26	—	Reserved
27:31	PITIRQL	Interrupt request level for PIT interrupts

6.6 Port Q

When not used as interrupt inputs, the $\overline{\text{IRQ[0:6]}}$/PQ[0:6] pins can be used for general-purpose I/O. The following registers control port Q operation:

- Port Q Pin Assignment Register (PQPAR) — allows the user to configure each pin as a digital input, digital output, edge- or level-sensitive interrupt request to the

CPU, or edge- or level-sensitive interrupt request to the interrupt controller.

- Port Q Edge Detect/Data Register (PQEDGDAT) — contains the following fields:
  - — The port Q data field (PQ[0:6]) monitors or controls the state of port Q pins, depending on the encoding for each pin in the PQPAR.
  - — The port Q edge-detect status field (PQE[0:6]) monitors when the proper transition occurs on a port Q or interrupt request pin.

6.6.1 Port Q Edge Detect/Data Register

The port Q edge detect/data register (PQEDGDAT) consists of the port Q edge-detect status field (PQE[0:6]) and the port Q data field (PQ[0:6]).

Port Q edge status (PQE) bits indicate when the proper transition has occurred on a port Q pin. Each pin can be configured as an interrupt input or as digital I/O. If the pin is configured in the PQPAR as an edge-sensitive interrupt request pin, then the PQE bit acts as a status bit that indicates whether the corresponding interrupt request line is asserted. The bit also acts as a status bit if the pins are configured as general-purpose inputs or outputs. When the pin is configured in edge-detect mode, the status bit is cleared by reading the bit as a one and then writing it to zero. In level-sensitive mode, the bit remains cleared.

A write to the port Q data register is stored in the internal data latch, and if any PQ bit is configured as an output, the value latched for that bit is driven onto the pin. A read of this port returns the value at the pin only if the pin is configured as a discrete input. Otherwise, the value read is the value stored in the internal data latch. The port Q data register can be read or written at any time.

PQEDGDAT — Port Q Edge Detect/Data Register **0x8007 EFD0**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PQE0	PQE1	PQE2	PQE3	PQE4	PQE5	PQE6	0	PQ0	PQ1	PQ2	PQ3	PQ4	PQ5	PQ6	0
RESET:															
U	U	0	0	0	0	0	0	U	U	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED															
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

U = Unaffected by reset

6.6.2 Port Q Pin Assignment Register

The port Q pin assignment register (PQPAR) contains the port Q pin assignment fields (PQPA[0:6]) and the port Q edge fields (PQEDGE[0:6]).

PQPAR — Port Q Pin Assignment Register **0x8007 EFD4**

0 1	2 3	4 5	6 7	8 9	10 11	12 13	14 15
PQPA0	PQEDGE0	PQPA1	PQEDGE1	PQPA2	PQEDGE2	PQPA3	PQEDGE3
RESET:							
0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

16 17	18 19	20 21	22 23	24 25	26 27	28 29	30 31
PQPA4	PQEDGE4	PQPA5	PQEDGE5	PQPA6	PQEDGE6	PQPA7	PQEDGE7
RESET:							
0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

6.6.2.1 Port Q Pin Assignment Fields

The port Q pin assignment fields (PQPA[0:6]) select the basic function of each port Q pin, as shown in **Table 6-7**.

Table 6-7 Port Q Pin Assignments

PQPA Value	Pin Function	PORTQ (Port Q Data Field)	Interrupt Request Source
0b00	General-Purpose Input	A read returns the state of the pin. A write has no effect.	None
0b01	General-Purpose Output	A read returns the value in the latch. A write drives the value in the latch onto the pin.	None
0b10	$\overline{\text{IRQ}}$ to CPU	A read returns the state of the pin. A write has no effect.	From pin if PQEDG field is set to “Level”, otherwise from port Q edge detect logic
0b11	$\overline{\text{IRQ}}$ to Interrupt Controller	A read returns the state of the pin. A write has no effect.	From pin if PQEDG field is set to “Level”, otherwise from port Q edge detect logic

6.6.2.2 Port Q Edge Fields

The port Q edge (PQEDGE[0:6]) fields select whether the port/interrupt pin is edge sensitive or level sensitive. When the selected transition occurs on a port Q pin, a corresponding status bit is set in the PQEDGDAT register.

Table 6-8 explains the encodings for PQEDGE fields.

Table 6-8 Port Q Edge Select Field Encoding

PQEDGE Value	Edge Select	PORTQE (Port Q Edge Detect Field)
00	Level sensitive	Returns zero when read
01	Falling-edge sensitive	Set on rising edge
10	Rising-edge sensitive	Set on falling edge
11	Either-edge sensitive	Set on either edge

SECTION 7
STATIC RAM MODULE

The static RAM (SRAM) module consists of a 4-Kbyte block of static RAM. The primary function of this module is to serve as fast (one-cycle access), general-purpose RAM for the MCU. The SRAM can be read or written as either bytes, half-words or words.

The bus interface and control logic for the SRAM module are powered by V_{DD}. A separate pin, VDDKAP2, supplies power to the memory arrays. If main power is shut off, VDDKAP2 can be maintained in order to retain the data in the SRAM array. When the main power is off, access to the SRAM array is blocked.

7.1 Features

- Fast, One-Cycle Access
- Low-Power Mode
  - — Two-Cycle Access
  - — Pipelined for Back-to-Back Accesses
- Programmable Attributes (Supervisor Only, Data Only, Read Only)

7.2 Placement of SRAM in Memory Map

The SRAM module consists of two separately addressable sections. The first is the array itself. The second section is a set of registers used for configuration and testing of the SRAM array.

The SRAM array is assigned to one of four locations in the MCU address map by programming the LMEMBASE field in the SIU internal memory mapping register (MEMMAP).

Note that the user must reserve the entire 32-Kbyte block containing the selected 4-Kbyte block of SRAM. **Table 7-1** indicates the location of the SRAM array and the associated reserved locations for each value of LMEMBASE.

Table 7-1 MPC509 SRAM Module Addresses

LMEMBASE	SRAM Location	Reserved Location
00	0x0000 0000 – 0x0000 6FFF	0x0000 7FFF – 0x0000 7FFF
01	0x000F 8000 – 0x000F EFFF	0x000F F000 – 0x000F FFFF
10	0xFFF0 0000 – 0xFFF0 6FFF	0xFFF0 7FFC – 0xFFF0 7FFF
11	0xFFFF 8000 – 0xFFFF EFFF	0xFFFF F000 – 0xFFFF FFFF

Refer to **5.2 SIU Module Configuration** for a diagram of the MEMMAP register.

Figure 7-1, a memory map of the MPC509, shows the possible locations of the SRAM array.

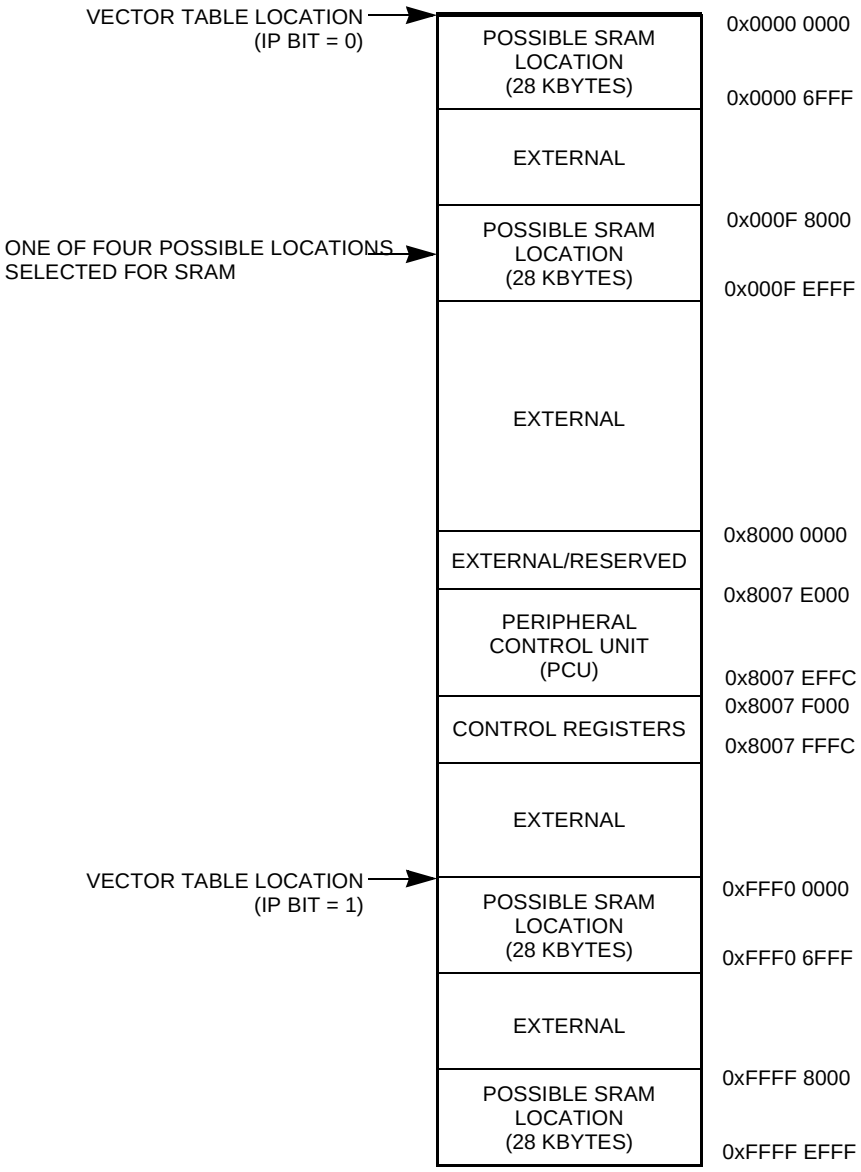


Figure 7-1 Placement of Internal SRAM in Memory Map

7.3 SRAM Registers

The control block for the SRAM module contains one control register for configuring the array and one control register for use in testing.

SRAMMCR — SRAM Module Configuration Register **0x8007 F000**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LCK	DIS	2CY	RESERVED												
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED				R0	D0	S0	RESERVED								
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Each SRAM module configuration register contains bits for setting access rights to the array. **Table 7-2** provides definitions for the bits.

Table 7-2 SRAMMCR Bit Settings

Bit(s)	Name	Description
0	LCK	Lock bit 0 = Writes to the SRAMMCR are accepted. 1 = Writes to the SRAMMCR are ignored.
1	DIS	Module disable 0 = SRAM module is enabled. 1 = SRAM module is disabled. Module can be subsequently re-enabled by software setting this bit or by reset. Attempts to read SRAM array when it is disabled result in internal $\overline{\text{TEA}}$ assertion.
2	2CY	Two-cycle mode 0 = SRAM module is in single-cycle mode (normal operation). 1 = SRAM module is in two-cycle mode. In this mode, the first cycle is used for decoding the address, and the second cycle is used for accepting or providing data. This mode provides some power savings while keeping the memory active.
3:19	—	Reserved
20	R0	Read only 0 = 4-Kbyte block is readable and writable. 1 = 4-Kbyte block is read only. Attempts to write to this space result in internal $\overline{\text{TEA}}$ assertion.
21	D0	Data only 0 = 4-Kbyte block can contain data or instructions. 1 = 4-Kbyte block contains data only. Attempts to load instructions from this space result in internal $\overline{\text{TEA}}$ assertion.
22	S0	Supervisor only 0 = 4-Kbyte block is placed in unrestricted space. 1 = 4-Kbyte block is placed in supervisor space. Attempts to access this space from the user privilege level result in internal $\overline{\text{TEA}}$ assertion.
23:31	—	Reserved

SRAMTST — SRAM Test Register **0x8007 F004**

The SRAM test register is used for factory testing only.

SECTION 8
DEVELOPMENT SUPPORT

Development tools are used by a microcomputer system developer to debug the hardware and software of a target system. These tools are used to give the developer some control over the execution of the target program. In-circuit emulators and bus state analyzers are the most frequently used debugging tools. In order for these tools to function properly, they must have full visibility of the microprocessor's buses.

Visibility extends beyond the address and data portions of the buses and includes attribute and handshake signals. In some cases it may also include bus arbitration signals and signals which cause processor exceptions such as interrupts and resets. The visibility requirements of emulators and bus analyzers are in opposition to the trend of modern microcomputers and microprocessors where the CPU bus may be hidden behind a memory management unit or cache or where bus cycles to internal resources are not visible externally.

The development tool visibility requirements may be reduced if some of the development support functions are included in the silicon. For example, if the bus comparator part of a bus analyzer or breakpoint generator is included on the chip, it is not necessary for the entire bus to be visible at all times. In many cases the visibility requirements may be reduced to instruction fetch cycles for tracking program execution. If some additional status information is also available to assist in execution tracking and the development tool has access to the source code, then the only need for bus visibility is often the destination address of indirect change-of-flow instructions (return from subroutine, return from interrupt, and indexed branches and jumps).

Since full bus visibility reduces available bus bandwidth and processor performance, certain development support functions have been included in the MCU. These functions include the following:

- Controls to limit which internal bus cycles are reflected on the external bus (show cycles)
- CPU status signals to allow instruction execution tracking with minimal visibility of the instructions being fetched
- Watchpoint comparators that can generate breakpoints or signal an external bus analyzer
- A serial development port for general emulation control

8.1 Program Flow Tracking

The exact program flow is visible on the external bus only when the processor is programmed to show all fetch cycles on the external bus. This mode is selected by programming the ISCTL (instruction fetch show cycle control) field in the I-bus support control register (ICTRL), as shown in **Table 8-2**. In this mode, the processor is fetch

serialized, and all internal fetch cycles appear on the external bus. Processor performance is therefore much lower than when working in regular mode.

The mechanism described below allows tracking of the program instructions flow with almost no performance degradation. The information provided externally may be captured and compressed and then parsed by a post-processing program using the microarchitecture defined below.

The RCPU implements a prefetch queue combined with parallel, out of order, pipelined execution. Instructions progress inside the processor from fetch to retire. An instruction retires from the machine only after it, and all preceding instructions, finish execution with no exception. Therefore only retired instructions can be considered architecturally executed.

These features, together with the fact that most fetch cycles are performed internally (e.g. from the I-cache), increase performance but make it very difficult to provide the user with the real program trace.

In order to reconstruct a program trace, the program code and the following additional information from the MCU are needed:

- A description of the last fetched instruction (stall, sequential, branch not taken, branch direct taken, branch indirect taken, exception taken).
- The addresses of the targets of all indirect flow change. Indirect flow changes include all branches using the link and count registers as the target address, all exceptions, and **rfi** and **mtmsr** because they may cause a context switch.
- The number of instructions canceled each clock.

Reporting on program trace during retirement would significantly complicate the visibility support and increase the die size. (Complications arise because more than one instruction can retire in a clock cycle, and because it is harder to report on indirect branches during retirement.) Therefore, program trace is reported during fetch. Since not all fetched instructions eventually retire, an indication on canceled instructions is reported.

Instructions are fetched sequentially until branches (direct or indirect) or exceptions appear in the program flow or some stall in execution causes the machine not to fetch the next address. Instructions may be architecturally executed, or they may be canceled in some stage of the machine pipeline.

The following sections define how this information is generated and how it should be used to reconstruct the program trace. The issue of data compression that could reduce the amount of memory needed by the debug system is also mentioned.

8.1.1 Indirect Change-of-Flow Cycles

An *indirect change-of-flow* attribute is attached to all fetch cycles that result from indirect flow changes. Indirect flow changes include the following types of instructions or events:

- Assertion or negation of VSYNC.

- Exception taken.
- Indirect branch taken.
- Execution of the following sequential instructions: **rfi**, **isync**, **mtmsr**, and **mtspr** to CMPA–CMPF, ICTRL, ECR, and DER.

When a program trace recording is needed, the user can ensure that cycles which result from an indirect change-of-flow are visible on the external bus. The user can do this in one of two ways: by setting the VSYNC bit, or by programming the ISCTL bits in the I-bus support control register. Refer to 8.1.2 Instruction Fetch Show Cycle Control for more information.

When the processor is programmed to generate show cycles on the external bus resulting from indirect change-of-flow, these cycles can generate regular bus cycles (address phase and data phase) when the instructions reside in one of the external devices, or they can generate address-only show cycles for instructions that reside in an internal device such as I-cache or internal ROM.

8.1.1.1 Marking the Indirect Change-of-Flow Attribute

When an instruction fetch cycle that results from an indirect change-of-flow is an internal access (e.g., access to an internal memory location, or a cache hit during an access to an external memory address), the indirect change-of-flow attribute is indicated by the assertion (low) of the $\overline{WR}$ pin during the external bus show cycle.

When an instruction fetch cycle that results from an indirect change-of-flow is an access to external memory not resulting in a cache hit, the indirect change-of-flow attribute is indicated by the value 0001 on the CT[0:3] pins.

Table 8-1 summarizes the encodings that represent the indirect change-of-flow attribute. In all cases the AT1 pin is asserted (high), indicating the cycle is an instruction fetch cycle.

Table 8-1 Program Trace Cycle Attribute Encodings

CT[0:3]	AT1	WR	Type of Bus Cycle
0001	1	1	External bus cycle
01xx, 10xx, 110x	1	0	Show cycle on the external bus reflecting an access to internal register or memory or a cache hit

Refer to 8.1.3 Program Flow-Tracking Pins for more information on the use of these pins for program flow tracking.

8.1.1.2 Sequential Instructions with the Indirect Change-of-Flow Attribute

Because certain sequential instructions (**rfi**, **isync**, **mtmsr**, and **mtspr** to CMPA–CMPF, ICTRL, ECR, and DER) affect the machine in a manner similar to indirect branch instructions, the processor marks these instructions as indirect branch instructions (VF = 101, see **Table 8-3**) and marks the subsequent instruction address with the indirect change-of-flow attribute, as if it were an indirect branch target. Therefore, when the processor detects one of these instructions, the address of the following

instruction is visible externally. This enables the reconstructing software to correctly evaluate the effect of these instructions.

8.1.2 Instruction Fetch Show Cycle Control

Instruction fetch show cycles are controlled by the bits in the ICTRL and the state of VSYNC, as illustrated in **Table 8-2**.

Table 8-2 Fetch Show Cycles Control

VSYNC	ISCTL (Instruction Fetch Show Cycle Control Bits)	Show Cycles Generated
X	00	All fetch cycles
X	01	All change-of-flow (direct & indirect)
X	10	All indirect change-of-flow
0	11	No show cycles are performed
1	11	All indirect change-of-flow

Note that when the value of the ISCTL field is changed (with the **mtspr** instruction), the new value does not take effect until two instructions after the **mtspr** instruction. The instruction immediately following **mtspr** is under control of the old ISCTL value.

In order to keep the pin count of the chip as low as possible, VSYNC is not implemented as an external pin; rather, it is asserted and negated using the development port serial interface. For more information on this interface refer to 8.3.5 Trap-Enable Input Transmissions.

The assertion and negation of VSYNC forces the machine to synchronize and the first fetch after this synchronization to be marked as an indirect change-of-flow cycle and to be visible on the external bus. This enables the external hardware to synchronize with the internal activity of the processor.

When either VSYNC is asserted or the ISCTL bits in the I-bus control register are programmed to a value of 0b10, cycles resulting from an indirect change-of-flow are shown on the external bus. By programming the ISCTL bits to show all indirect flow changes, the user can thus ensure that the processor maintains exactly the same behavior when VSYNC is asserted as when it is negated. The loss of performance the user can expect from the additional external bus cycles is minimal.

For additional information on the ISCTL bits and the ICTRL register, refer to 8.8 Development Support Registers. For more information on the use of VSYNC during program trace, refer to 8.1.4 External Hardware During Program Trace.

8.1.3 Program Flow-Tracking Pins

The following sets of pins are used in program flow tracking:

- Instruction queue status pins (VF[0:2]) denote the type of the last fetched instruction or how many instructions were flushed from the instruction queue.
- History buffer flushes status pins (VFLS [0:1]) denote how many instructions were

flushed from the history buffer during the current clock cycle.

- Address type pin 1 (AT1) indicates whether the cycle is transferring an instruction or data.
- The write/read pin ($\overline{WR}$), when asserted during an instruction fetch show cycle, indicates the current cycle results from an indirect change-of-flow.
- Cycle type pins (CT[0:3]) indicate the type of bus cycle and are used to determine the address of an internal memory or register that is being accessed.

8.1.3.1 Instruction Queue Status Pins

Instruction queue status pins VF[0:2] indicate the type of the last fetched instruction or how many instructions were flushed from the instruction queue. These status pins are used for both functions because queue flushes occur only during clock cycles in which there is no fetch type information to be reported.

Table 8-3 shows the possible instruction types.

Table 8-3 VF Pins Instruction Encodings

VF[0:2]	Instruction Type	VF Next Clock Will Hold
000	None	More instruction type information
001	Sequential	More instruction type information
010	Branch (direct or indirect) **not** taken	More instruction type information
011	VSYNC was asserted/negated and therefore the next instruction will be marked with the indirect change-of-flow attribute	More instruction type information
100	Exception taken — the target will be marked with the program trace cycle attribute	Queue flush information[1]
101	Branch indirect taken, **rfi**, **mtmsr**, **isync** and in some cases **mtspr** to CMPA-F, ICTRL, ECR, or DER — the target will be marked with the indirect change-of-flow attribute[2]	Queue flush information[1]
110	Branch direct taken	Queue flush information[1]
111	Branch (direct or indirect) **not** taken	Queue flush information[1]

NOTES:

1. Unless next clock VF = 111. See below.
2. The sequential instructions listed here affect the machine in a manner similar to indirect branch instructions. Refer to **8.1.1.2 Sequential Instructions with the Indirect Change-of-Flow Attribute**.

Table 8-4 shows VF[0:2] encodings for instruction queue flush information.

Table 8-4 VF Pins Queue Flush Encodings

VF[0:2]	Queue Flush Information
000	0 instructions flushed from instruction queue
001	1 instruction flushed from instruction queue
010	2 instructions flushed from instruction queue
011	3 instructions flushed from instruction queue
100	4 instructions flushed from instruction queue
101	5 instructions flushed from instruction queue
110	Reserved
111	Instruction type information[1]

NOTES:
1. Refer to **Table 8-3**.

There is one special case in which although queue flush information is expected on the VF[0:2] pins (according to the immediately preceding value on these pins), regular instruction type information is reported. The only instruction type information that can appear in this case is VF[0:2] = 111, indicating branch (direct or indirect) not taken. Since the maximum queue flushes possible is five, identifying this special case is not a problem.

8.1.3.2 History Buffer Flush Status Pins

History buffer flush status pins VFLS[0:1] indicate how many instructions are flushed from the history buffer this clock. **Table 8-4** shows VFLS encodings.

Table 8-5 VFLS Pin Encodings

VFLS[0:1]	History Buffer Flush Information
00	0 instructions flushed from history queue
01	1 instruction flushed from history queue
10	2 instructions flushed from history queue
11	Used for debug mode indication (FREEZE). Program trace external hardware should ignore this setting.

8.1.3.3 Flow-Tracking Status Pins in Debug Mode

When the processor is in debug mode, the VF[0:2] signals are low (000) and the VFLS[0:1] signals are high (11).

If VSYNC is asserted or negated while the processor is in debug mode, this information is reported as the first VF pins report when the processor returns to regular mode. If VSYNC is not changed while the processor is in debug mode, the first VF pins report is of an indirect branch taken (VF[0:2] = 101), appropriate for the **rfi** instruction that is being issued. In both cases, the first instruction fetch after debug mode is marked with the program trace cycle attribute and therefore is visible externally.

8.1.3.4 Cycle Type, Write/Read, and Address Type Pins

Cycle type pins (CT[0:3]) indicate the type of bus cycle being performed. During show cycles, these pins are used to determine the internal address being accessed. **Table 8-6** summarizes cycle type encodings.

Table 8-6 Cycle Type Encodings

CT[0:3]	Description
0000	Normal external bus cycle
0001	If address type is data (AT1 = 0), this is a data access to the external bus and the start of a reservation. If address type is instruction (AT1 = 1), this cycle type indicates that an external address is the destination of an indirect change-of-flow.
0010	External bus cycle to emulation memory replacing internal I-bus or L-bus memory. An instruction access (AT1 = 1) with an address that is the target of an indirect change-of-flow is indicated as a logic level zero on the $\overline{WR}$ output.
0011	Normal external bus cycle access to a port replacement chip used for emulation support.
0100	Access to internal I-bus memory. An instruction access (AT1 = 1) with an address that is the target of an indirect change-of-flow is indicated as a logic level zero on the $\overline{WR}$ output.
0101	Access to internal L-bus memory. An instruction access (AT1 = 1) with an address that is the target of an indirect change-of-flow is indicated as a logic level zero on the $\overline{WR}$ output.
0110	Cache hit on external memory address not controlled by chip selects. An instruction access (AT1 = 1) with an address that is the target of an indirect change-of-flow is indicated as a logic level zero on the $\overline{WR}$ output.
0111	Access to an internal register.
1000 1001 1010 1011 1100 1101	Cache hit on external memory address controlled by $\overline{CSBOOT}$. Cache hit on external memory address controlled by $\overline{CS1}$. Cache hit on external memory address controlled by $\overline{CS2}$. Cache hit on external memory address controlled by $\overline{CS3}$. Cache hit on external memory address controlled by $\overline{CS4}$. Cache hit on external memory address controlled by $\overline{CS5}$. An instruction access (AT1 = 1) with an address that is the target of an indirect change-of-flow is indicated as a logic level zero on the $\overline{WR}$ output.
1110	Reserved
1111	

Notice in **Table 8-6** that during an instruction fetch (AT1 = 1) to internal memory or to external memory resulting in a cache hit, a logic level of zero on the $\overline{WR}$ pin indicates that the cycle is the result of an indirect change-of-flow. The indirect change-of-flow attribute is also indicated by a cycle type encoding of 0001 when AT1 = 1. Refer to 8.1.1.1 Marking the Indirect Change-of-Flow Attribute for additional information.

8.1.4 External Hardware During Program Trace

When program trace is needed, external hardware needs to record the status pins (VF[0:2] and VFLS[0:1]) of each clock and record the address of all cycles marked with the indirect change-of-flow attribute.

Program trace can be used in various ways. Two types of traces that can be implemented are the back trace and the window trace.

8.1.4.1 Back Trace

A back trace provides a record of the program trace *before* some event occurred. An example of such an event is some system failure.

When a back trace is needed, the external hardware should start sampling the status pins and the address of all cycles marked with the indirect change-of-flow attribute immediately after reset is negated. Since the ISCTL field in the ICTRL has a value of is 0b00 (show all cycles) out of reset, all cycles marked with the indirect change-of-flow attribute are visible on the external bus. VSYNC should be asserted sometime after reset and negated when the programmed event occurs. VSYNC must be asserted before the ISCTL encoding is changed to 0b11 (no show cycles), if such an encoding is selected.

Note that in case the timing of the programmed event is unknown, it is possible to use cyclic buffers.

After VSYNC is negated, the trace buffer will contain the program flow trace of the program executed before the programmed event occurred.

8.1.4.2 Window Trace

Window trace provides a record of the program trace *between* two events. VSYNC should be asserted between these two events.

After VSYNC is negated, the trace buffer will contain information describing the program trace of the program executed between the two events.

8.1.4.3 Synchronizing the Trace Window to Internal CPU Events

In order to synchronize the assertion or negation of VSYNC to an event internal to the processor, internal breakpoints can be used together with debug mode. This method is available only when debug mode is enabled. (Refer to 8.4 Debug Mode Functions.)

The following steps enable the user to synchronize the trace window to events internal to the processor:

1. Enter debug mode, either immediately out of reset or using the debug mode request.
2. Program the hardware to break on the event that marks the start of the trace window using the control registers defined in 8.8 Development Support Registers.
3. Enable debug mode entry for the programmed breakpoint in the debug enable register (DER).
4. Return to the regular code run.
5. The hardware generates a breakpoint when the programmed event is detected, and the machine enters debug mode.
6. Program the hardware to break on the event that marks the end of the trace

window.
7. Assert VSYNC.
8. Return to the regular code run. The first report on the VF pins is a VSYNC (VF[0:2] = 011).
9. The external hardware starts sampling the program trace information upon the report on the VF pins of VSYNC.
10. The hardware generates a breakpoint when the programmed event is detected, and the machine enters debug mode.
11. Negate VSYNC.
12. Return to the regular code run. The first report on the VF pins is a VSYNC (VF[0:2] = 011).
13. The external hardware stops sampling the program trace information upon the report on the VF pins of VSYNC.

A second method allows the trace window to be synchronized to internal processor events without stopping execution and entering debug mode at the two events.

1. Enter debug mode, either immediately out of reset or using the debug mode request.
2. Program a watchpoint for the event that marks the start of the trace window using the control registers defined in 8.8 Development Support Registers.
3. Program a second watchpoint for the event that marks the end of the trace window.
4. Return to regular code execution by exiting debug mode.
5. The watchpoint logic signals the starting event by asserting the appropriate watchpoint pin.
6. Upon detecting the first watchpoint, assert VSYNC using the development port serial interface.
7. The external program trace hardware starts sampling the program trace information upon the report on the VF pins of VSYNC.
8. The watchpoint logic signals the ending event by asserting the appropriate watchpoint pin.
9. Upon detecting the second watchpoint, negate VSYNC using the development port serial interface.
10. The external program trace hardware stops sampling the program trace information upon the report on VF[0:1] of VSYNC.

The second method is not as precise as the first method because of the delay between the assertion of the watchpoint pins and the assertion or negation of VSYNC using the development port serial interface. It has the advantage, however, of allowing the program to run in quasi-real time (slowed only by show cycles on the external bus), instead of stopping execution at the starting and ending events.

8.1.4.4 Detecting the Trace Window Starting Address

For a back trace, the value of the status pins (VF[0:2] and VFLS[0:1]) and the address of the cycles marked with the indirect change-of-flow attribute should be latched starting immediately after the negation of reset. The starting address is the first address in the program trace cycle buffer.

For a window trace, the value of the status pins and the address of the cycles marked with the indirect change-of-flow attribute should be latched beginning immediately after the first VSYNC is reported on the VF pins. The starting address of the trace window should be calculated according to the first two VF pin reports.

Assume VF1 and VF2 are the two first VF pin reports and T1 and T2 are the addresses of the first two cycles marked with the indirect change-of-flow attribute that were latched in the trace buffer. Use **Table 8-7** to calculate the trace window starting address.

Table 8-7 Detecting the Trace Buffer Starting Point

VF1	VF2	Starting Point	Description
011 VSYNC	001 Sequential	T1	VSYNC asserted followed by a sequential instruction. The starting address is T1.
011 VSYNC	110 Branch direct taken	T1 – 4 + offset (T1 – 4)	VSYNC asserted followed by a taken direct branch. The starting address is the target of the direct branch.
011 VSYNC	101 Branch indirect taken	T2	VSYNC asserted followed by a taken indirect branch. The starting address is the target of the indirect branch.

8.1.4.5 Detecting the Assertion or Negation of VSYNC

Since the VF pins are used for reporting both instruction type information and queue flush information, special care must be taken when trying to detect the assertion or negation of VSYNC. A VF[0:2] encoding of 011 indicates the assertion or negation of VSYNC only if the previous VF[0:2] pin values were 000, 001, or 010.

8.1.4.6 Detecting the Trace Window Ending Address

The information on the VF and VFLS status pins changes every clock. Cycles marked with the indirect change-of-flow are generated on the external bus only when possible (when the SIU wins the arbitration over the external bus). Therefore, there is some delay between the time it is reported on the status pins that a cycle marked as program trace cycle will be performed on the external bus and the actual time that this cycle can be detected on the external bus.

When the user negates VSYNC, the processor delays the report of the assertion or negation of VSYNC on the VF pins until all addresses marked with the indirect change-of-flow attribute have been made visible externally. Therefore, the external hardware should stop sampling the value of the status pins (VF and VFLS) and the address of the cycles marked with the program trace cycle attribute immediately after the VSYNC report on the VF pins.

CAUTION

The last two instructions reported on the VF pins are not always valid. Therefore, at the last stage of the reconstruction software, the last two instructions should be ignored.

8.1.5 Compress

In order to store all the information generated on the pins during program trace (5 bits per clock + 30 bits per show cycle) a large memory buffer may be needed. However, since this information includes events that were canceled, compression can be very effective. External hardware can be added to eliminate all canceled instructions and report only on branches (taken and not taken), indirect flow change, and the number of sequential instructions after the last flow change.

8.2 Watchpoint and Breakpoint Support

The RCPU provides the ability to detect specific bus cycles, as defined by a user (watchpoints). It also provides the ability to conditionally respond to these watchpoints by taking an exception (internal breakpoints). Breakpoints can also be caused by an event or state in a peripheral or through the development port (external breakpoints, i.e., breakpoints external to the processor).

When a watchpoint is detected, it is reported to external hardware on dedicated pins. Watchpoints do not change the timing or flow of the processor. Because bus cycles on the internal MCU buses are not necessarily visible on the external bus, the watchpoints are a convenient way to signal an external instrument (such as a bus state analyzer or oscilloscope) that the internal bus cycle occurred.

An internal breakpoint occurs when a particular watchpoint is enabled to generate a breakpoint. A watchpoint may be enabled to generate a breakpoint from a software monitor or by using the development port serial interface. A watchpoint output may also be counted. When the counter reaches zero, an internal breakpoint is generated.

An external breakpoint occurs when a development system or external peripheral requests a breakpoint through the development port serial interface. In addition, if an on-chip peripheral requests a breakpoint, an external breakpoint is generated.

All internal breakpoints are masked by the MSR[RI] bit unless the non-masked control bit (BRKNOMSK) in LCTRL2 is set. The development port maskable breakpoint and breakpoints from internal peripherals are masked by the MSR[RI] bit. The development port non-maskable breakpoint is not masked by this bit.

Figure 8-1 is a diagram of watchpoint and breakpoint support in the RCPU.

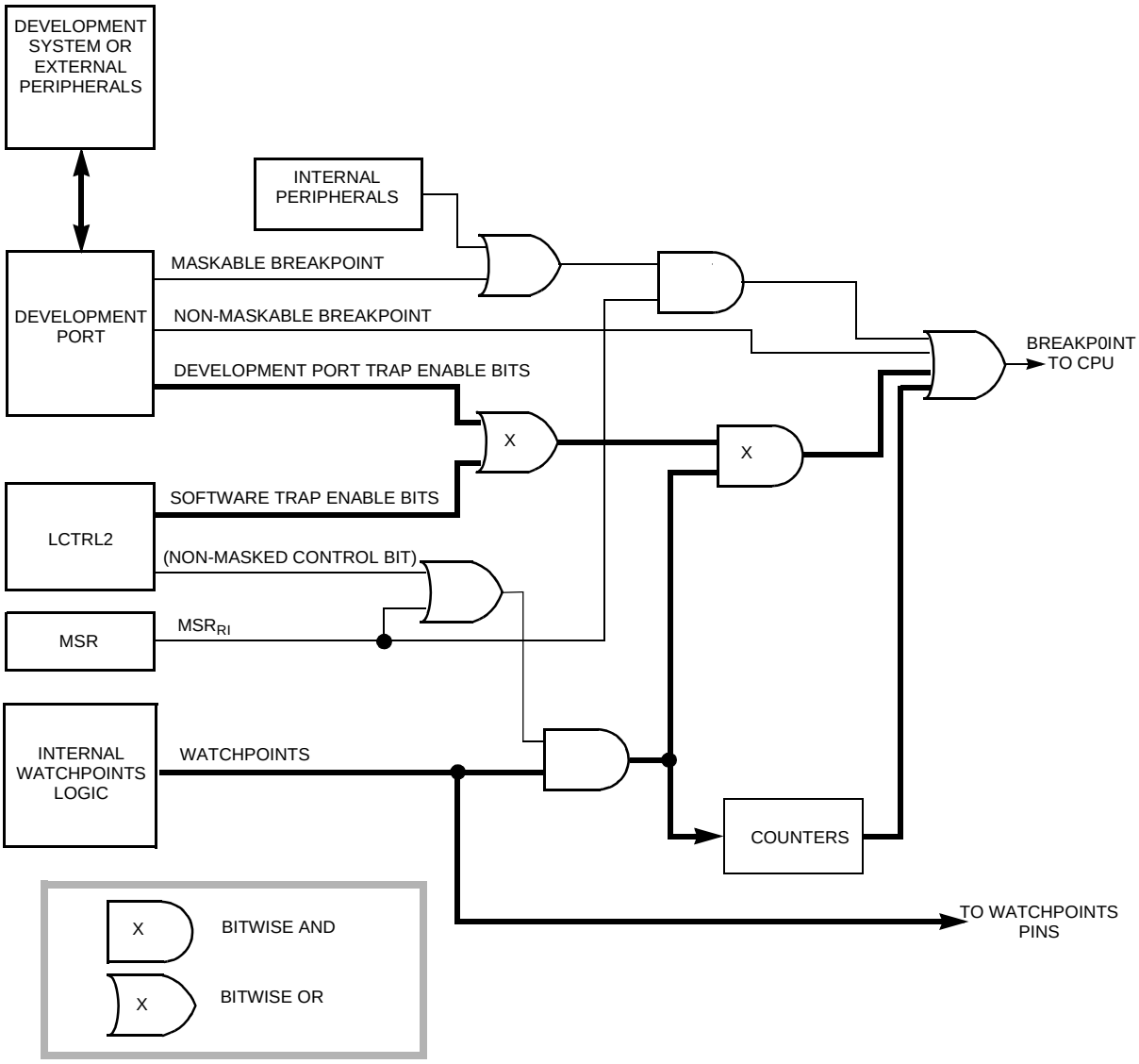


Figure 8-1 Watchpoint and Breakpoint Support in the RCPU

8.2.1 Watchpoints

Watchpoints are based on eight comparators on the I-bus and L-bus, two counters, and two AND-OR logic structures. There are four comparators on the instruction address bus (I-address), two comparators on the load/store address bus (L-address), and two comparators on the load/store data bus (L-data).

The comparators are able to detect the following conditions: equal, not equal, greater than, and less than. Greater than or equal and less than or equal are easily obtained from these four conditions. (For more information refer to 8.2.1.3 Generating Six Compare Types.) Using the AND-OR logic structures, in range and out of range detection (on address and on data) are supported. Using the counters, it is possible to program a breakpoint to be generated after an event is detected a predefined number of times.

The L-data comparators can operate on integer data, floating-point single-precision data, and the integer value stored using the **stfiwx** instruction. Integer comparisons can be performed on bytes, half words, and words. The operands can be treated as signed or unsigned values.

The comparators generate match events. The I-bus match events enter the I-bus AND-OR logic, where the I-bus watchpoints and breakpoint are generated. When asserted, the I-bus watchpoints may generate the I-bus breakpoint. Two of them may decrement one of the counters. When a counter that is counting one of the I-bus watchpoints expires, the I-bus breakpoint is asserted.

The I-bus watchpoints and the L-bus match events (address and data) enter the L-bus AND-OR logic where the L-bus watchpoints and breakpoint are generated. When asserted, the L-bus watchpoints may generate the L-bus breakpoint, or they may decrement one of the counters. When a counter that is counting one of the L-bus watchpoints expires, the L-bus breakpoint is asserted.

L-bus watchpoints can be qualified by I-bus watchpoints. If qualified, the L-bus watchpoint occurs only if the L-bus cycle was the result of executing an instruction that caused the qualifying I-bus watchpoint.

A watchpoint progresses in the machine along with the instruction that caused it (fetch or load/store cycle). Watchpoints are reported on the external pins when the associated instruction is retired.

8.2.1.1 Restrictions on Watchpoint Detection

There are cases when the same watchpoint can be detected more than once during the execution of a single instruction. For example, the processor may detect an L-bus watchpoint on more than one transfer when executing a load/store multiple or string instruction or may detect an L-bus watchpoint on more than one byte when working in byte mode. In these cases only one watchpoint of the same type is reported for a single instruction. Similarly, only one watchpoint of the same type can be counted in the counters for a single instruction.

Since watchpoint events are reported upon the retirement of the instruction that caused the event, and more than one instruction can retire from the machine in one clock, separate watchpoint events may be reported in the same clock. Moreover, the same event, if detected on more than one instruction (e.g. tight loops, range detection), in some cases is reported only once. However, the internal counters still count correctly.

8.2.1.2 Byte and Half-Word Working Modes

Watchpoint and breakpoint support enables the user to detect matches on bytes and half words even when accessed using a load/store instruction of larger data widths, e.g. when loading a table of bytes using a series of load word instructions.

To use this feature the user needs to program the byte mask for each of the L-data comparators and to write the needed match value to the correct half word of the data

comparator when working in half-word mode and to the correct bytes of the data comparator when working in byte mode.

Since bytes and half words can be accessed using a larger data width instruction, the user cannot predict the exact value of the L-address lines when the requested byte or half word is accessed. For example, if the matched byte is byte two of the word and it is accessed using a load word instruction, the L-address value will be of the word (byte zero). Therefore the processor masks the two least significant bits of the L-address comparators whenever a word access is performed and the least significant bit whenever a half word access is performed. Address range is supported only when aligned according to the access size.

The following examples illustrate how to detect matches on bytes and half words.

1. A fully supported scenario:
   - Looking for:
     - Data size: Byte
     - Address: 0x0000 0003
     - Data value: greater than 0x07 and less than 0x0C
   - Programming option:
     - One L-address comparator = 0x0000 0003 and program for equal
     - One L-data comparator = 0xXXXX XXX7 and program for greater than
     - One L-data comparator = 0xXXXX XXXC and program for less than
     - Both byte masks = 0b0001
     - Both L-data comparators program to byte mode
   - Result: The event will be detected regardless of the instruction the compiler chooses for this access.
2. A fully supported scenario:
   - Looking for:
     - Data size: Half word
     - Address: greater than 0x0000 0000 and less than 0x0000 000C
     - Data value: greater than 0x4E20 and less than 0x9C40
   - Programming option:
     - One L-address comparator = 0x0000 0000 and program for greater than
     - One L-address comparator = 0x0000 000C and program for less than
     - One L-data comparator = 0x4E20 4E20 and program for greater than
     - One L-data comparator = 0x9C40 9C40 and program for less than
     - Both byte masks = 0b1111
     - Both L-data comparators program to half word mode
   - Result: The event will be detected correctly provided that the compiler does not use a load/store instruction with data size of byte.
3. A partially supported scenario:
   - Looking for:
     - Data size: Half word
     - Address: greater than 0x0000 0002 and less than 0x0000 000E
     - Data value: greater than 0x4E20 and less than 0x9C40
   - Programming option:
     - One L-address comparator = 0x0000 0002 and program for greater than

— One L-address comparator = 0x0000 000E and program for less than
— One L-data comparator = 0x4E20 4E20 and program for greater than
— One L-data comparator = 0x9C40 9C40 and program for less than
— Both byte masks = 0b1111
— Both L-data comparators program to half-word mode or to word mode

4. Result: The event will be detected correctly if the compiler chooses a load/store instruction with data size of half word. If the compiler chooses load/store instructions with data size greater than half word (word, multiple), there might be some false detections. These can be ignored only by the software that handles the breakpoints. **Figure 8-2** illustrates this partially supported scenario.

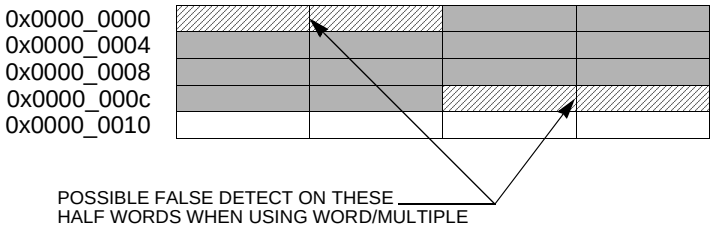


Figure 8-2 Partially Supported Watchpoint/Breakpoint Example

8.2.1.3 Generating Six Compare Types

Using the four basic compare types (equal, not equal, greater than, less than), it is possible to generate two additional compare types: “greater than or equal” and “less than or equal”.

The “greater than or equal” compare type can be generated using the greater than compare type and programming the comparator to the needed value minus one.

The “less than or equal” compare type can be generated using the less than compare type and programming the comparator to the needed value plus one.

This method does not work for the following boundary cases:

- Less than or equal of the largest unsigned number (1111...1)
- Greater than or equal of the smallest unsigned number (0000...0)
- Less than or equal of the maximum positive number when in signed mode (0111...1)
- Greater than or equal of the maximum negative number when in signed mode (1000...)

These boundary cases need no special support because they all mean “always true” and can be programmed using the ignore option of the L-bus watchpoint programming (refer to 8.8 Development Support Registers).

8.2.1.4 I-Bus Support Detailed Description

There are four I-bus address comparators (comparators A,B,C,D). Each is 30 bits long and generates two output signals: equal and less than. These signals are used to gen-

erate one of the following four events: equal, not equal, greater than, less than. **Figure 8-3** shows the general structure of I-bus support.

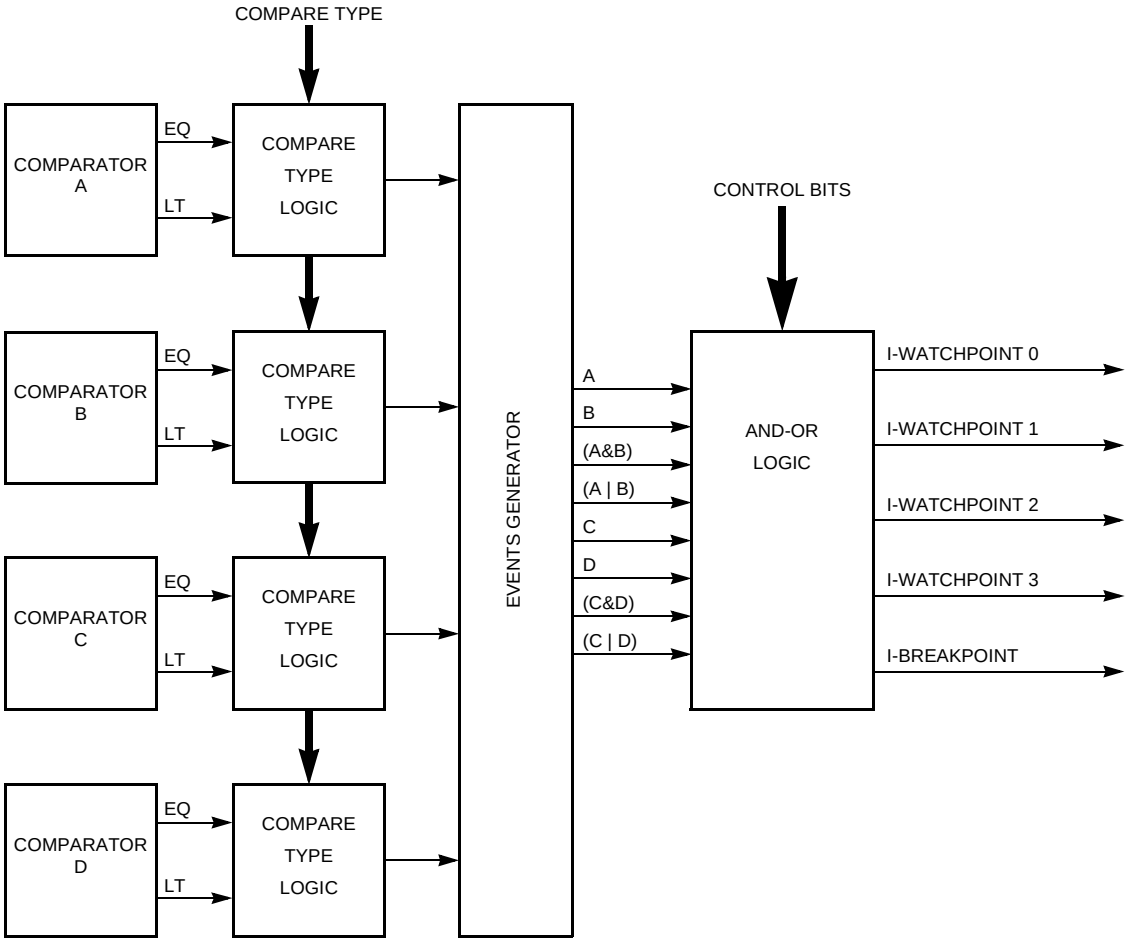


Figure 8-3 I-Bus Support General Structure

The I-bus watchpoints and breakpoint are generated using these events and according to the user's programming of the CMPA, CMPB, CMPC, CMPD, and ICTRL registers. **Table 8-8** shows how watchpoints are determined from the programming options. Note that using the OR option enables "out of range" detection.

Table 8-8 I-bus Watchpoint Programming Options

Name	Description	Programming Options
IW0	First I-bus watchpoint	Comparator A Comparators (A&B)
IW1	Second I-bus watchpoint	Comparator B Comparator (A | B)
IW2	Third I-bus watchpoint	Comparator C Comparators (C&D)
IW3	Fourth I-bus watchpoint	Comparator D Comparator (C | D)

8.2.1.5 L-Bus Support Detailed Description

There are two L-bus address comparators (comparators E and F). Each compares the 32 address bits and the cycle's read/write attribute. The two least significant bits are masked (ignored) whenever a word is accessed, and the least significant bit is masked whenever a half word is accessed. (For more information refer to 8.2.1.2 Byte and Half-Word Working Modes). Each comparator generates two output signals: equal and less than. These signals are used to generate one of the following four events (one from each comparator): equal, not equal, greater than, less than.

There are two L-bus data comparators (comparators G and H). Each is 32 bits wide and can be programmed to treat numbers either as signed values or as unsigned values. Each data comparator operates as four independent byte comparators. Each byte comparator has a mask bit and generates two output signals, equal and less than, if the mask bit is not set. Therefore, each 32-bit comparator has eight output signals.

These signals are used to generate the "equal and less than" signals according to the compare size programmed by the user (byte, half word, word). In byte mode all signals are significant. In half-word mode only four signals from each 32-bit comparator are significant. In word mode only two signals from each 32-bit comparator are significant.

From the new "equal and less than" signals, depending on the compare type programmed by the user, one of the following four match events is generated: equal, not equal, greater than, less than. Therefore from the two 32-bit comparators, eight match indications are generated: Gmatch[0:3], Hmatch[0:3].

According to the lower bits of the address and the size of the cycle, only match indications that were detected on bytes that have valid information are validated; the rest are negated. Note that if the cycle executed has a smaller size than the compare size (e.g., a byte access when the compare size is word or half word) no match indication is asserted.

Figure 8-4 shows the general structure of L-bus support.

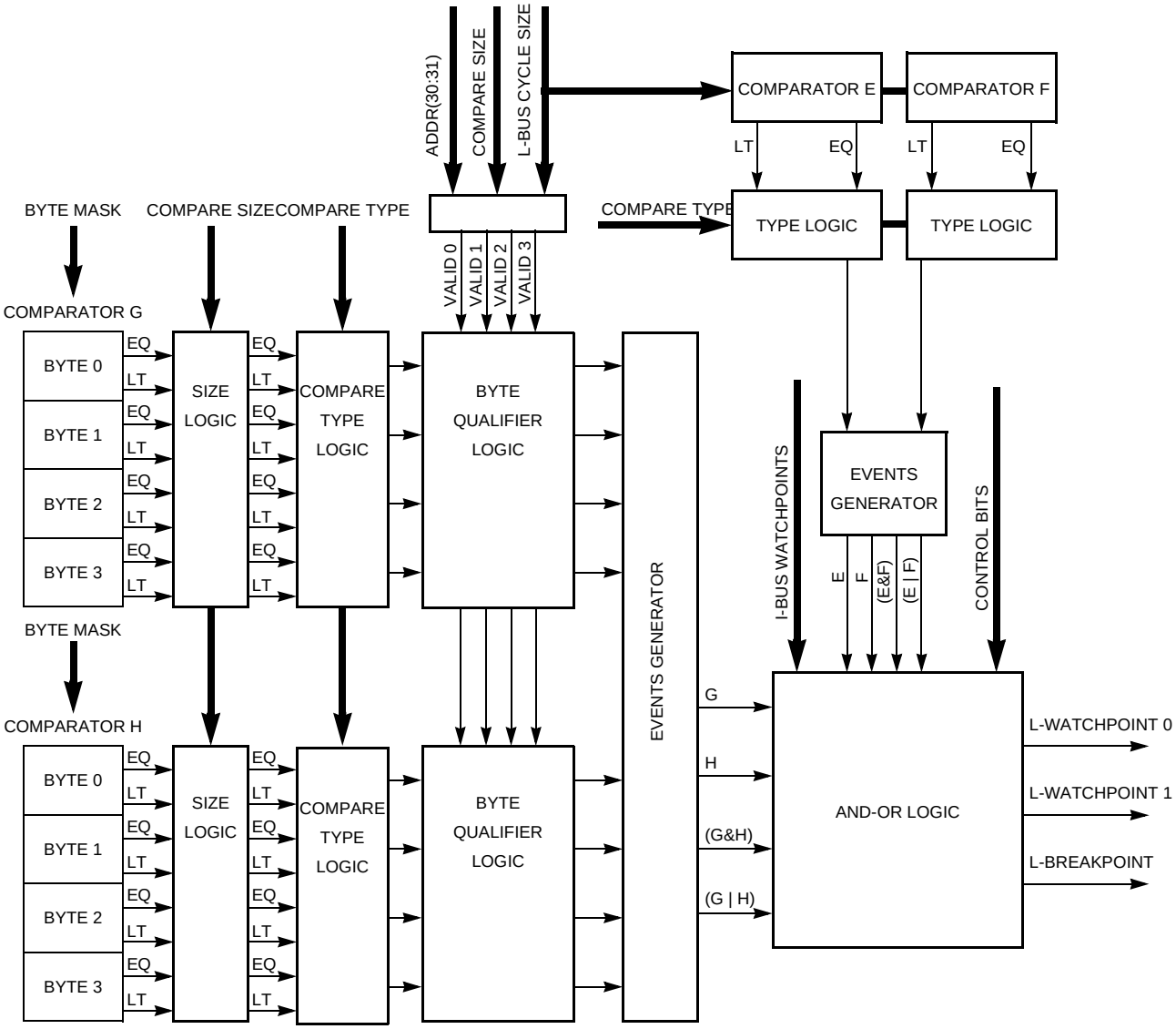


Figure 8-4 L-Bus Support General Structure

Using the match indication signals, four L-bus data events are generated as shown in **Table 8-9**.

Table 8-9 L-Bus Data Events

Event Name	Event Function[1]
G	(Gmatch0 | Gmatch1 | Gmatch2 | Gmatch3)
H	(Hmatch0 | Hmatch1 | Hmatch2 | Hmatch3)
(G&H)	((Gmatch0 & Hmatch0) | (Gmatch1 & Hmatch1) | (Gmatch2 & Hmatch2) | (Gmatch3 & Hmatch3))
(G | H)	((Gmatch0 | Hmatch0) | (Gmatch1 | Hmatch1) | (Gmatch2 | Hmatch2) | (Gmatch3 | Hmatch3))

NOTES:
1. '&' denotes a logical AND, '|' denotes a logical OR

The four L-bus data events together with the match events of the L-bus address comparators and the I-bus watchpoints are used to generate the L-bus watchpoints and breakpoint according to the user's programming of the CMPE, CMPF, CMPG, CMPH, LCTRL1, and LCTRL2 registers. **Table 8-10** shows how the watchpoints are determined from the programming options.

Table 8-10 L-Bus Watchpoints Programming Options

Name	Description	I-Bus Events Programming Options	L-Address Events Programming Options	L-Data Events Programming Options
LW0	First L-bus watchpoint	IW0, IW1, IW2, IW3 or don't care	Comparator E Comparator F Comparators (E&F) Comparators (E | F) or don't care	Comparator G Comparator H Comparators (G&H) Comparators (G | H) or don't care
LW1	Second L-bus watchpoint	IW0, IW1, IW2, IW3 or don't care	Comparator E Comparator F Comparators (E&F) Comparators (E | F) or don't care	Comparator G Comparator H Comparators (G&H) Comparators (G | H) or don't care

8.2.1.6 Treating Floating-Point Numbers

The data comparators can detect match events on floating-point single precision values in floating point load/store instructions. When floating point values are compared, the comparators must be programmed to operate in signed word mode.

During the execution of a load/store instruction of a floating-point double operand, the L-data comparators never generate a match. If L-data events are programmed for don't care (i.e., LCTRL2[LWOLADC] = 0), L-bus watchpoint and breakpoint events can be generated from the L-address events, even if the instruction is a load/store double instruction.

8.2.2 Internal Breakpoints

Internal breakpoints are generated from the watchpoints. The user may enable a watchpoint to create a breakpoint by setting the associated software trap enable bit in the ICTRL or LCTRL2 register. This can be done by a software monitor program executed by the MCU. An external development tool can also enable internal breakpoints from watchpoints by setting the associated development port trap enable bit using the development port serial interface.

Internal breakpoints can also be generated by assigning a breakpoint counter to a particular watchpoint. The counter counts down for each watchpoint, and a breakpoint is generated when the counter reaches zero.

An internal breakpoint progresses in the machine along with the instruction that caused it (fetch or load/store cycle). When a breakpoint reaches the top of the history buffer, the machine processes the breakpoint exception.

An instruction that causes an I-bus breakpoint is not retired. The processor branches to the breakpoint exception routine *before* it executes the instruction. An instruction

that causes an L-bus breakpoint is executed. The processor branches to the breakpoint exception routine *after* it executes the instruction. The address of the load/store cycle that generated the L-bus breakpoint is stored in the breakpoint address register (BAR).

8.2.2.1 Breakpoint Counters

There are two 16-bit down counters. Each counter is able to count one of the I-bus watchpoints or one of the L-bus watchpoints. Both generate the corresponding breakpoint when they reach zero. If the instruction associated with the watchpoint is not retired, the counter is adjusted back so that it reflects actual execution.

In the masked mode, the counters do not count watchpoints detected when MSR[RI] = 0. See 8.2.4 Breakpoint Masking.

When counting watchpoints programmed on the actual instructions that alter the counters, the counters will have unpredictable values. A **sync** instruction should be inserted before a read of an active counter.

8.2.2.2 Trap-Enable Programming

The trap enable bits can be programmed by regular, supervisor-level software (by writing to the ICTRL or LCTRL2 with the **mtspr** instruction) or “on the fly” using the development port interface. For more information on the latter method, refer to **8.3.5 Trap-Enable Input Transmissions**.

The value used by the breakpoints generation logic is the bit-wise OR of the software trap enable bits (the bits written using the **mtspr)** and the development port trap enable bits (the bits serially shifted using the development port).

All bits, the software trap-enable bits and the development port trap enable bits, can be read from ICTRL and the LCTRL2 using **mfspr**. For the exact bits placement refer to **Table 8-30** and **Table 8-32**.

8.2.2.3 Ignore First Match

In order to facilitate the debugger utilities of “continue” and “go from x”, the option to ignore the first match is supported for the I-bus breakpoints. When an I-bus breakpoint is first enabled (as a result of the first write to the I-bus support control register or as a result of the assertion of the MSR[RI] bit in masked mode), the first instruction will not cause an I-bus breakpoint if the IFM (ignore first match) bit in the I-bus support control register (ICTRL) is set (used for “continue”). This allows the processor to be stopped at a breakpoint and then later to “continue” from that point without the breakpoint immediately stopping the processor again before executing the first instruction.

When the IFM bit is cleared, every matched instruction can cause an I-bus breakpoint (used for “go from x,” where x is an address that would not cause a breakpoint).

The IFM bit is set by the software and cleared by the hardware after the first I-bus breakpoint match is ignored.

Since L-bus breakpoints are treated after the instruction is executed, L-bus breakpoints and counter-generated I-bus breakpoints are not affected by this mode.

8.2.3 External Breakpoints

Breakpoints external to the processor can come from either an on-chip peripheral or from the development port. For additional information on breakpoints from on-chip peripherals, consult the user's manual for the microcontroller of interest or the reference manual for the peripheral of interest.

The development port serial interface can be used to assert either a maskable or non-maskable breakpoint. Refer to 8.3.5 Trap-Enable Input Transmissions for more information about generating breakpoints from the development port. The development port breakpoint bits remain asserted until they are cleared; however, they cause a breakpoint only when they change from cleared to set. If they remain set, they do not cause an additional breakpoint until they are cleared and set again.

External breakpoints are not referenced to any particular instruction; they are referenced to the current or following L-bus cycle. The breakpoint is taken as soon as the processor completes an instruction that uses the L-bus.

8.2.4 Breakpoint Masking

The processor responds to two different types of breakpoints. The maskable breakpoint is taken only if the processor is in a recoverable state. This means that taking the breakpoint will not destroy any of the internal machine context. The processor is defined to be in a recoverable state when the MSR[RI] (recoverable exception) bit is set. Maskable breakpoints are generated by the internal breakpoint logic, modules on the IMB2, and the development port.

Non-maskable breakpoints cause the processor to stop without regard to the state of the MSR[RI] bit. If the processor is in a non-recoverable state when the breakpoint occurs, the state of the SRR0, SRR1, and the DAR may have been overwritten by the breakpoint. It will not be possible to restart the processor, since the restart address and MSR context may not be available in SRR0 and SRR1.

Only the development port and the internal breakpoint logic are capable of generating a non-maskable breakpoint. This allows the user to stop the processor in cases where it would otherwise not stop, but with the penalty that it may not be restartable. The value of the MSR[RI] bit as saved in the SRR1 register indicates whether the processor stopped in a recoverable state or not.

Internal breakpoints are made maskable or non-maskable by clearing or setting the BRKNOMSK bit of the LCTRL2 register. Refer to 8.8.7 L-Bus Support Control Register 2.

8.3 Development Port

The development port provides a full duplex serial interface for communications between the internal development support logic, including debug mode, and an external development tool.

The relationship of the development support logic to the rest of the MCU is shown in Figure 8-5. Although the development port is implemented as part of the system interface unit (SIU), it is used in conjunction with RCPU development support features and is therefore described in this section.

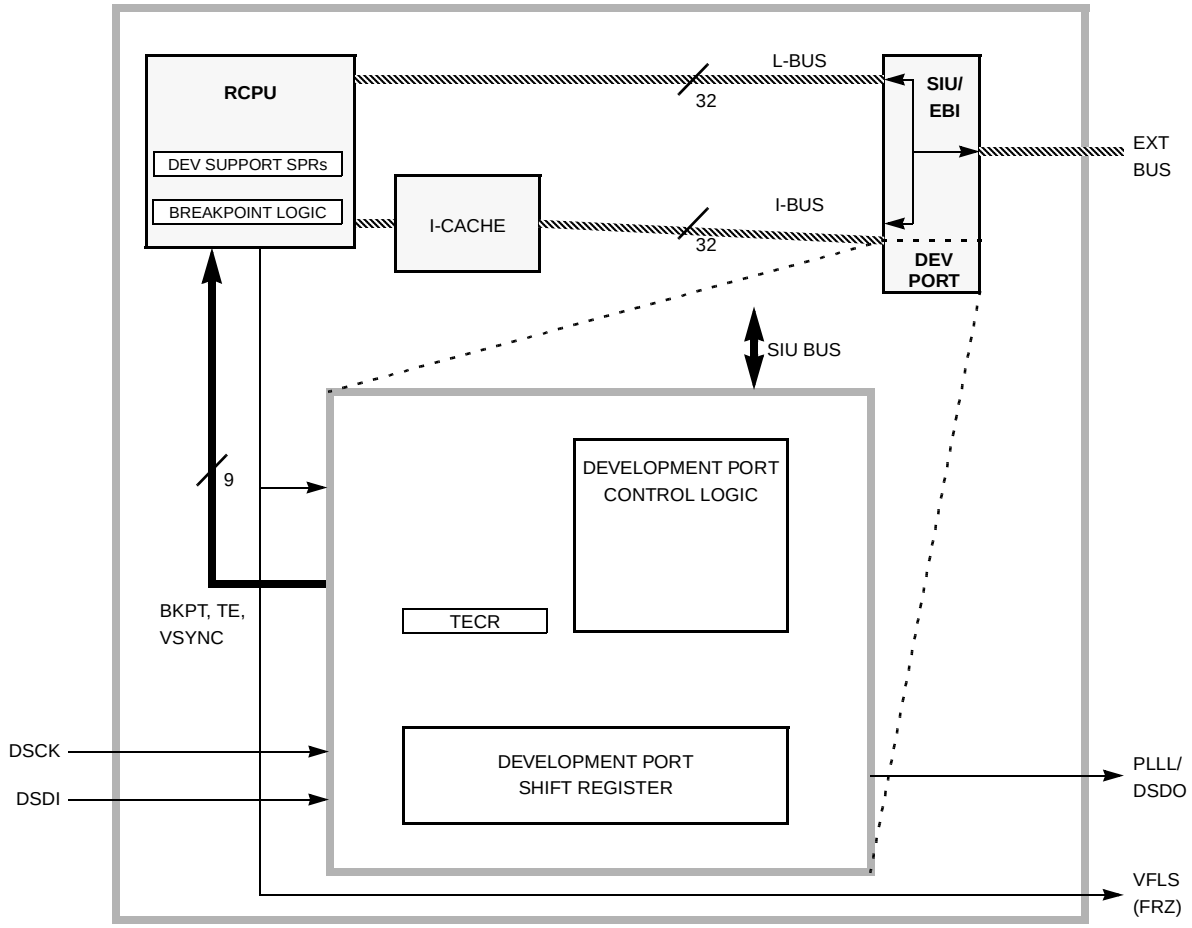


Figure 8-5 Development Port Support Logic

8.3.1 Development Port Signals

The following development port signals are provided:

- Development serial clock (DSCK)
- Development serial data in (DSDI)
- Development serial data out (DSDO)

The development port signal DSDO shares a pin with the PLLL signal.

8.3.1.1 Development Serial Clock

In clocked mode (see 8.3.3 Development Port Clock Mode Selection), the development serial clock (DSCK) is used to shift data into and out of the development port shift register. The DSCK and DSDI inputs are synchronized to the on-chip system clock, thereby minimizing the chance of propagating metastable states into the serial state machine. The values of the pins are sampled during the low phase of the system clock. At the rising edge of the system clock, the sampled values are latched internally. One quarter clock later, the latched values are made available to the development support logic.

In clocked mode, detection of the rising edge of the synchronized clock causes the synchronized data from the DSDI pin to be loaded into the least significant bit of the shift register. This transfer occurs one quarter clock after the next rising edge of the system clock. At the same time, the new most significant bit of the shift register is presented at the PLLL/DSDO pin. Future references to the DSCK signal imply the internal synchronized value of the clock. The DSCK input must be driven either high or low at all times and not allowed to float. A typical target environment would pull this input low with a resistor.

To allow the synchronizers to operate correctly, the development serial clock frequency must not exceed one half of the system clock frequency. The clock may be implemented as a free-running clock. The shifting of data is controlled by ready and start signals so the clock does not need to be gated with the serial transmissions. Refer to 8.3.5 Trap-Enable Input Transmissions and 8.3.6 CPU Input Transmissions.

The DSCK pin is also used during reset to enable debug mode and immediately following reset to optionally cause immediate entry into debug mode following reset. This is described in section 8.4.1 Enabling Debug Mode and 8.4.2 Entering Debug Mode.

8.3.1.2 Development Serial Data In

Data to be transferred into the development port shift register is presented at the development serial data in (DSDI) pin by external logic. To be sure that the correct value is used internally, transitions on the DSDI pin should occur at least a setup time ahead of the rising edge of the DSCK signal (if in clocked mode) or a setup time ahead of the rising edge of the system clock, whichever is greater. This will allow operation of the development port either asynchronously or synchronously with the system clock. The DSDI input must be driven either high or low at all times and not allowed to float. A typical target environment would pull this input low with a resistor.

When the processor is not in debug mode (freeze not indicated on VFLS[0:1] pins) the data received on the DSDI pin is transferred to the trap enable control register. When the processor is in debug mode, the data received on the DSDI pin is provided to the debug mode interface. Refer to 8.3.5 Trap-Enable Input Transmissions and **8.3.6 CPU Input Transmissions** for additional information.

The DSDI pin is also used at reset to control overall chip reset configuration and immediately following reset to determine the development port clock mode. See **8.3.3 Development Port Clock Mode Selection** for more information.

8.3.1.3 Development Serial Data Out

When the processor is not in reset, the development port shifts data out of the development port shift register using the development serial data out (PLLL/DSDO) pin. When the processor is in reset, the PLLL/DSDO pin indicates the state of lock of the system clock phase-locked loop. This can be used to determine when a reset is caused by a loss of lock on the system clock PLL.

8.3.2 Development Port Registers

The development port consists of two registers: the development port shift register and the trap enable control register. These registers are described in the following paragraphs. **Figure 8-6** illustrates the development port registers and data paths.

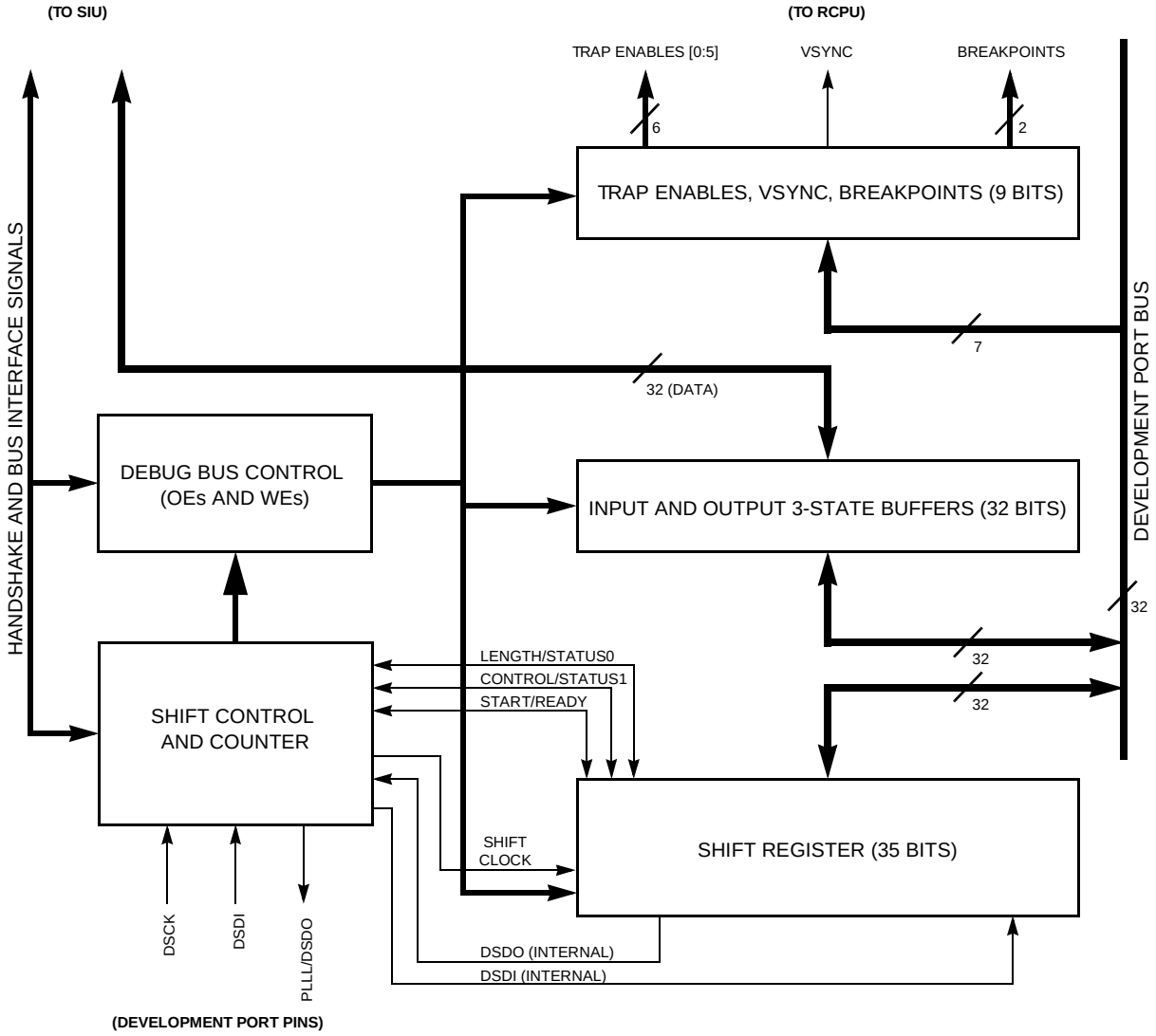


Figure 8-6 Development Port Registers and Data Paths

8.3.2.1 Development Port Shift Register

The development port shift register is a 35-bit shift register. Instructions and data are shifted into it serially from DSDI. These instructions or data are then transferred in parallel to the processor or the trap enable control register (TECR).

When the processor enters debug mode, it fetches instructions from the development port shift register. These instructions are serially loaded into the shift register from DSDI.

When the processor is in debug mode, data is transferred to the CPU by shifting it into the shift register. The processor then reads the data as the result of executing a “move from special-purpose register DPDR” (development port data register) instruction.

In debug mode, data is also parallel loaded into the development port shift register from the CPU by executing a “move to special purpose register DPDR” instruction. It is then shifted out serially to PLLL/DSDO.

8.3.2.2 Trap Enable Control Register

The trap enable control register (TECR) is a nine-bit register that is loaded from the development port shift register. The contents of the TECR are used to drive the six trap enable signals, the two breakpoint signals, and the VSYNC signal to the processor. Trap-enable transmissions to the development port cause the appropriate bits of the development port shift register to be transferred to the control register.

8.3.3 Development Port Clock Mode Selection

All of the development port serial transmissions are clocked transmissions. The transmission clock can be either synchronous or asynchronous with the system clock (CLKOUT). The development port supports three methods for clocking the serial transmissions. The first method allows the transmission to occur without being externally synchronized with CLKOUT but at more restricted data rates. The two faster communication methods require the clock and data to be externally synchronized with CLKOUT.

The first clock mode is called *asynchronous clocked* since the input clock (DSCK) is asynchronous with CLKOUT. The input synchronizers on the DSCK and DSDI pins sample the inputs to ensure that the signals used internally have no metastable oscillations. To be sure that data on DSDI is sampled correctly, transitions on DSDI must occur a setup time ahead of the rising edge of DSCK. Data on DSDI must also be held for one CLKOUT cycle plus one hold time after the rising edge of DSCK. This ensures that after the signals have passed through the input synchronizers, the data will be valid at the rising edge of the serial clock even if DSCK and DSDI do not meet the setup and hold time requirements of the pins.

Asynchronous clocked mode allows communications with the port from a development tool that does not have access to the CLKOUT signal or where the CLKOUT signal has been delayed or skewed. Because of the asynchronous nature of the inputs and the setup and hold time requirements on DSDI, this clock mode must be clocked at a frequency less than or equal to one third of CLKOUT.

The second clock mode is called *synchronous clocked* because the input clock and input data meet all setup and hold time requirements with respect to CLKOUT. Since the input synchronizers must sample the input clock in both the high and low state, DSCK cannot be faster than one half of CLKOUT.

The third clock mode is called *synchronous self-clocked* because it does not require an input clock. Instead, the port is clocked by the system clock. The DSDI input is required to meet all setup and hold time requirements with respect to CLKOUT. The data rate for this mode is always the same as the system clock rate, which is at least twice as fast as in synchronous clocked mode. In this mode, an undelayed CLKOUT signal must be available to the development tool, and extra care must be taken to avoid noise and crosstalk on the serial lines.

The selection of clocked or self-clocked mode is made immediately following reset. The state of the DSDI input is latched eight clocks after $\overline{\text{RESETOUT}}$ is negated. If it is latched low, external clocked mode is enabled. If it is latched high, then self-clocked mode is enabled. When external clocked mode is enabled, the use of asynchronous or synchronous mode is determined by the design of the external development tool.

Since DSDI is used during reset to configure the MCU and to select the development port clocking scheme, it is necessary to prevent any transitions on DSDI during this time from being recognized as the start of a serial transmission. The port does not begin scanning for the start bit of a serial transmission until 16 clocks after the negation of $\overline{\text{RESETOUT}}$. If DSDI is asserted 16 clocks after $\overline{\text{RESETOUT}}$ negation, the port will wait until DSDI is negated to begin scanning for the start bit.

The selection of clocked/self-clocked mode is shown in **Figure 8-7**. The timing diagrams in **Figure 8-8**, **Figure 8-9**, and **Figure 8-10** show the serial communications for both trap enable mode and debug mode for all clocking schemes.

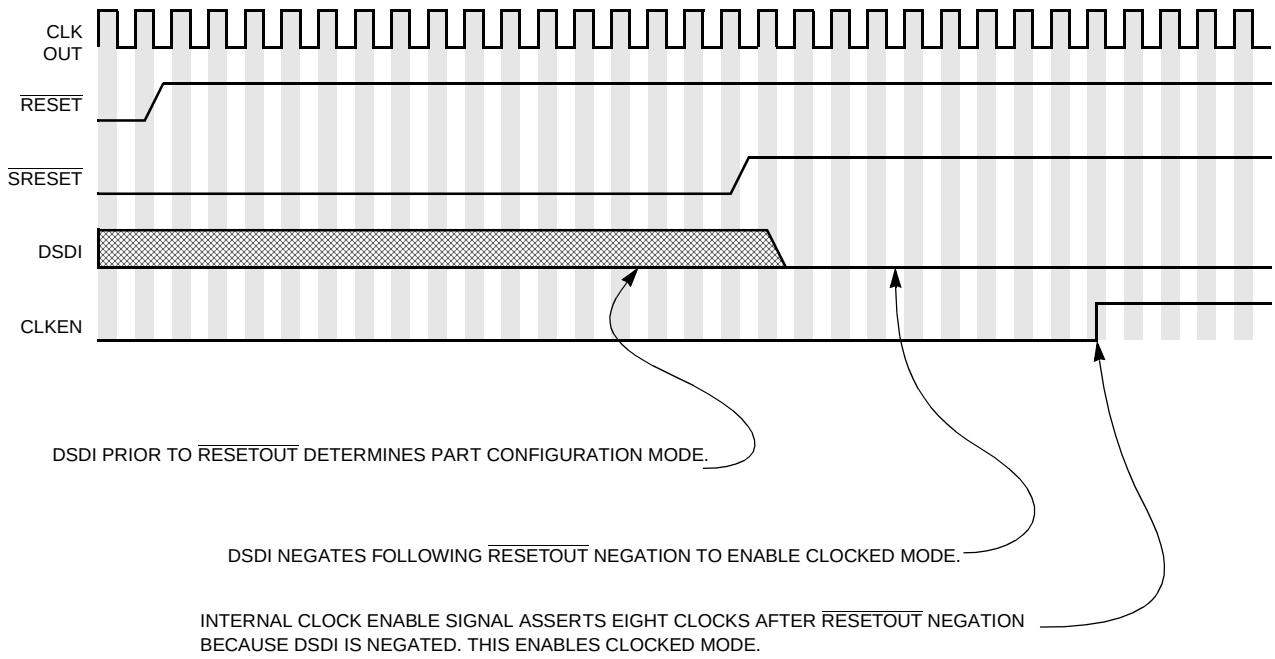

CLK OUT
RESET
SRESET
DSDI
CLKEN
DSDI PRIOR TO RESETOUT DETERMINES PART CONFIGURATION MODE.
DSDI NEGATES FOLLOWING RESETOUT NEGATION TO ENABLE CLOCKED MODE.
INTERNAL CLOCK ENABLE SIGNAL ASSERTS EIGHT CLOCKS AFTER RESETOUT NEGATION
BECAUSE DSDI IS NEGATED. THIS ENABLES CLOCKED MODE.

Figure 8-7 Enabling Clock Mode Following Reset

Examples of serial communications using the three clock modes are shown in **Figure 8-8**, **Figure 8-9**, and **Figure 8-10**.

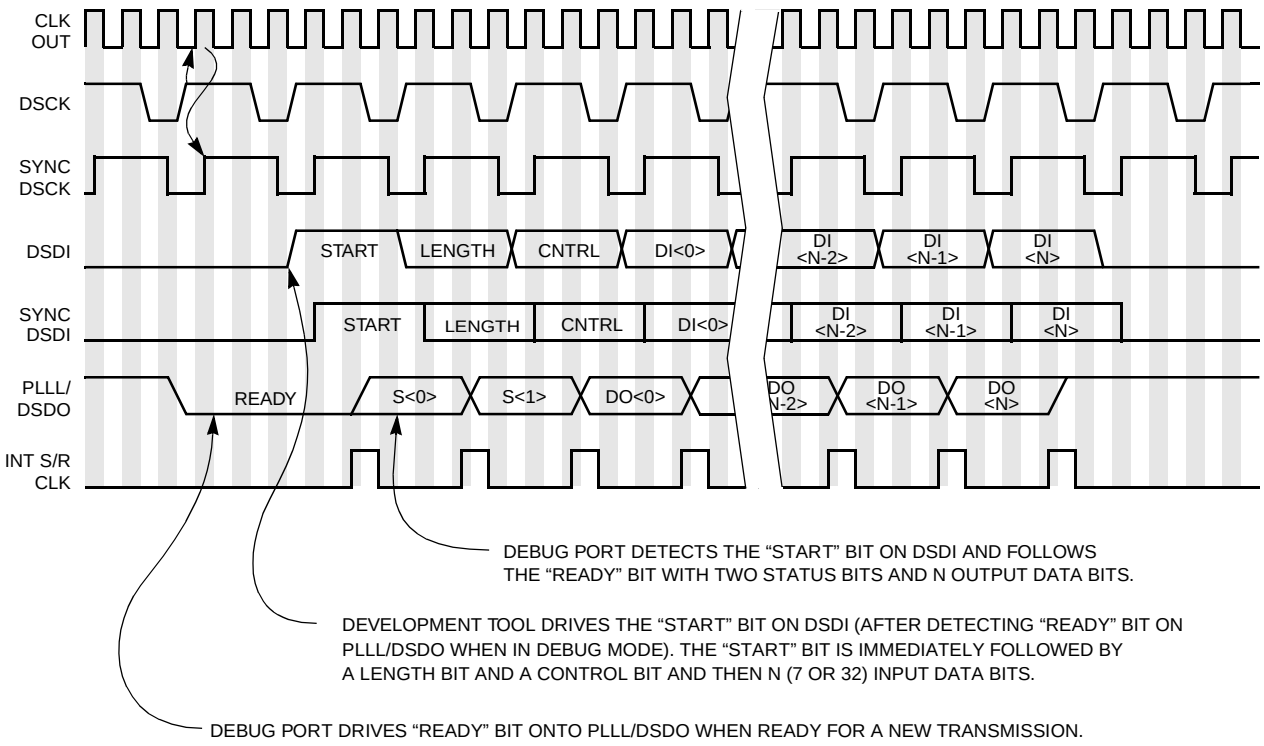


Figure 8-8 Asynchronous Clocked Serial Communications

In **Figure 8-8**, the frequency on the DSCK pin is equal to CLKOUT frequency divided by three. This is the maximum frequency allowed for the asynchronous clocked mode. DSCK and DSDI transitions are not required to be synchronous with CLKOUT.

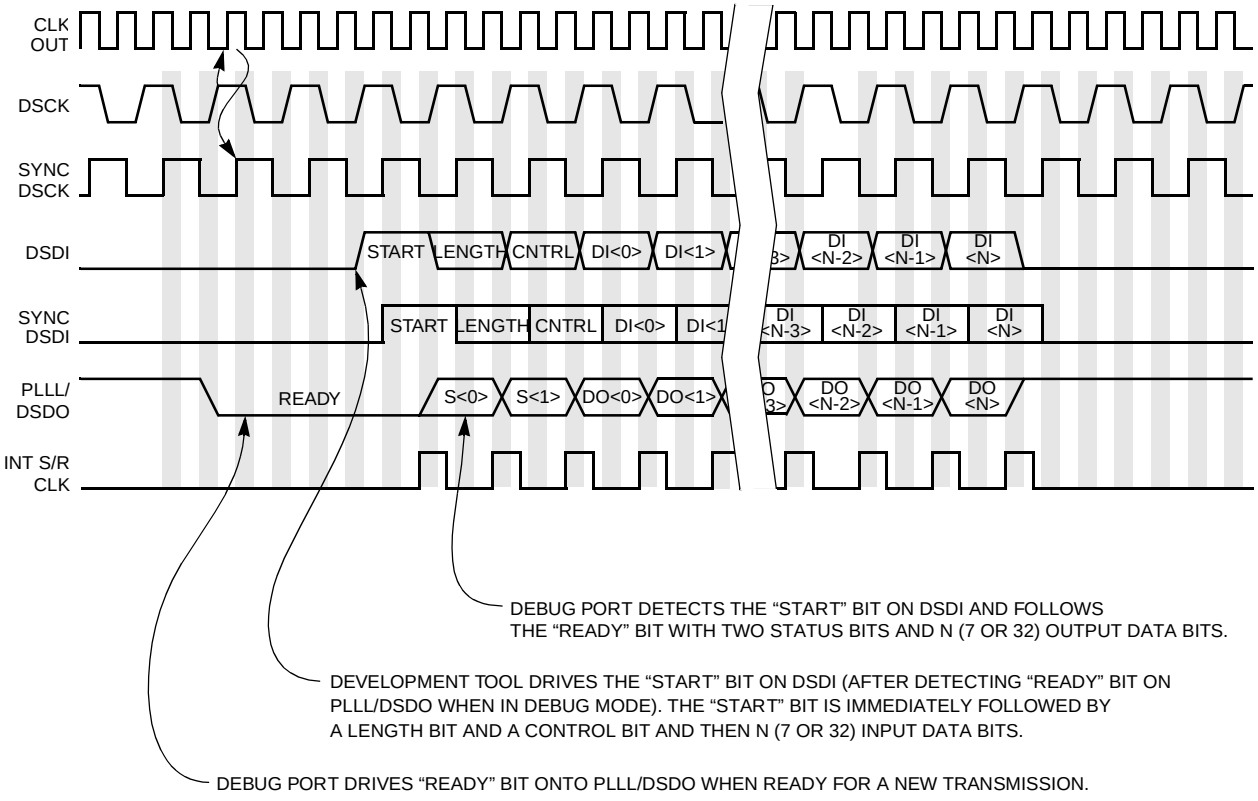

CLK OUT
DSCK
SYNC DSCK
DSDI
START
LENGTH
CNTRL
DI<0>
DI<1>
DI <N-2>
DI <N-1>
DI <N>
SYNC DSDI
DI <N-3>
PLLL/ DSDO
READY
S<0>
S<1>
DO<0>
DO<1>
DO <N-2>
DO <N-1>
DO <N>
INT S/R CLK
DEBUG PORT DETECTS THE “START” BIT ON DSDI AND FOLLOWS THE “READY” BIT WITH TWO STATUS BITS AND N (7 OR 32) OUTPUT DATA BITS.
DEVELOPMENT TOOL DRIVES THE “START” BIT ON DSDI (AFTER DETECTING “READY” BIT ON PLLL/DSDO WHEN IN DEBUG MODE). THE “START” BIT IS IMMEDIATELY FOLLOWED BY A LENGTH BIT AND A CONTROL BIT AND THEN N (7 OR 32) INPUT DATA BITS.
DEBUG PORT DRIVES “READY” BIT ONTO PLLL/DSDO WHEN READY FOR A NEW TRANSMISSION.

Figure 8-9 Synchronous Clocked Serial Communications

In **Figure 8-9**, the frequency on the DSCK pin is equal to CLKOUT frequency divided by two. DSDI and DSCK transitions must meet setup and hold timing requirements with respect to CLKOUT.

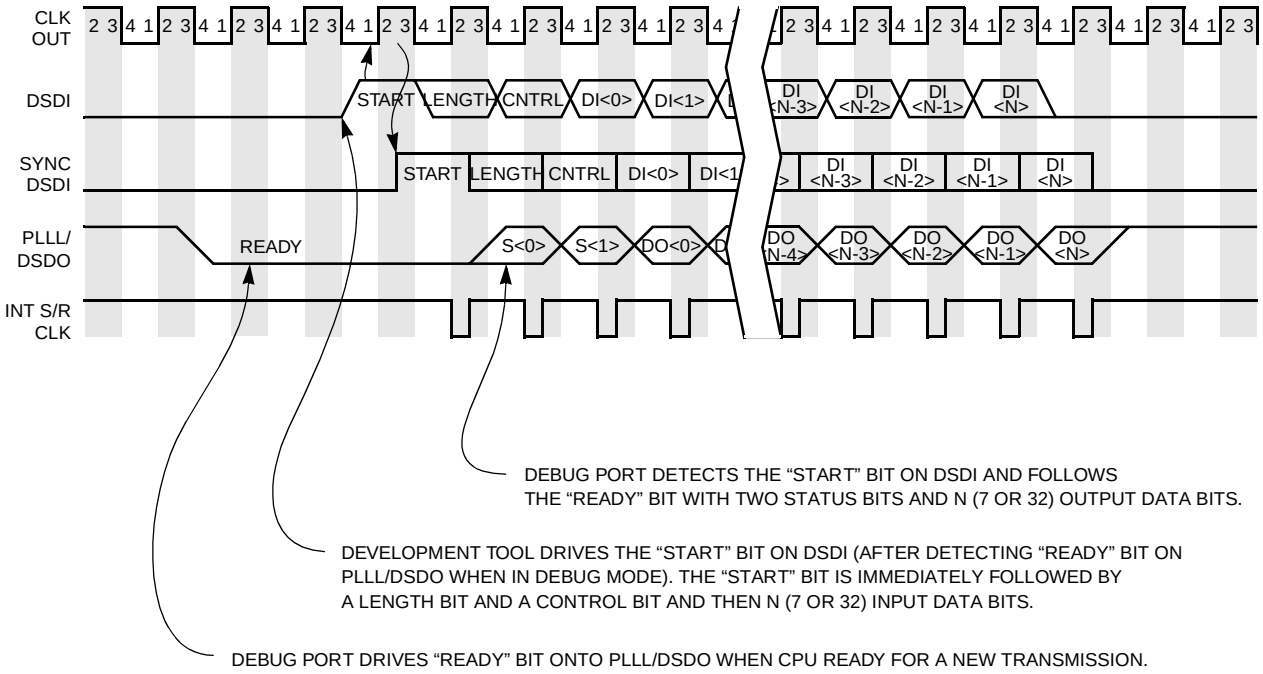

CLK OUT
DSDI
SYNC DSDI
PLLL/ DSDO
INT S/R CLK
START
LENGTH
CNTRL
DI<0>
DI<1>
READY
S<0>
S<1>
DO<0>
DEBUG PORT DETECTS THE “START” BIT ON DSDI AND FOLLOWS THE “READY” BIT WITH TWO STATUS BITS AND N (7 OR 32) OUTPUT DATA BITS.
DEVELOPMENT TOOL DRIVES THE “START” BIT ON DSDI (AFTER DETECTING “READY” BIT ON PLLL/DSDO WHEN IN DEBUG MODE). THE “START” BIT IS IMMEDIATELY FOLLOWED BY A LENGTH BIT AND A CONTROL BIT AND THEN N (7 OR 32) INPUT DATA BITS.
DEBUG PORT DRIVES “READY” BIT ONTO PLLL/DSDO WHEN CPU READY FOR A NEW TRANSMISSION.

Figure 8-10 Synchronous Self-Clocked Serial Communications

In **Figure 8-10**, the DSCK pin is not used, and the transmission is clocked by CLKOUT. DSDI transitions must meet setup and hold timing requirements with respect to CLKOUT.

8.3.4 Development Port Transmissions

The development port starts communications by setting PLLL/DSDO (the *ready* bit, or MSB of the 35-bit development port shift register) low to indicate that all activity related to the previous transmission is complete and that a new transmission may begin. The start of a serial transmission from an external development tool to the development port is signaled by a *start* bit on the DSDI pin.

The start bit also signals the development port that it can begin driving data on the DSDO pin. While data is shifting into the LSB of the shift register from the DSDI pin, it is simultaneously shifting out of the MSB of the shift register onto the DSDO pin.

A *length* bit defines the transmission as being to either the trap-enable register (length bit = 1, indicating seven data bits) or the CPU (length bit = 0, indicating 32 data bits). Transmissions of data and instructions to the CPU are allowed only when the processor is in debug mode. The two types of transmissions are discussed in 8.3.5 Trap-Enable Input Transmissions and 8.3.6 CPU Input Transmissions.

8.3.5 Trap-Enable Input Transmissions

If the length bit is set, the input transmission will only be ten bits long. These trap-enable transmissions into the development port include a start bit, a length bit, a control bit, and seven data bits. Only the seven data bits are shifted into the 35-bit shift

register. These seven bits are then latched into the TECR. The control bit determines whether the data is latched into the trap enable and VSYNC bits of the TECR or into the breakpoints bits of the TECR, as shown in **Table 8-11** and **Table 8-12**.

Table 8-11 Trap Enable Data Shifted Into Development Port Shift Register

Start	Length	Control	1st	2nd	3rd	4th	1st	2nd	VSYNC	Usage
			I-bus				L-bus			
			Watchpoint Trap Enables							
1	1	0	0 = disabled; 1 = enabled							Input data for trap enable control register

Table 8-12 Breakpoint Data Shifted Into Development Port Shift Register

Start	Length	Control	Non-Maskable	Maskable	Reserved bits					Usage
			Breakpoints							
1	1	1	0 = negate; 1 = assert		1	1	1	1	1	Input data for trap enable control register

8.3.6 CPU Input Transmissions

If the length bit in the serial input sequence is cleared, the transmission is an input to the CPU. This transmission type is legal only when the processor is in debug mode.

For transmissions to the CPU, the 35 bits of the development port shift register are interpreted as a start bit, a length bit, a control bit, and 32 bits of instructions or data. The encoding of data shifted into the development port shift register (through the DSDI pin) is shown in **Table 8-13**.

Table 8-13 CPU Instructions/Data Shifted into Shift Register

Start	Length	Control	Instruction/Data (32 Bits)	Usage
1	0	0	CPU Instruction	Input instruction for the CPU
1	0	1	CPU Data	Input data for the CPU

The control bit differentiates between instructions and data and allows the development port to detect that an instruction was entered when the CPU was expecting data and vice versa. If this occurs, a sequence error indication is shifted out in the next serial transmission.

8.3.7 Serial Data Out of Development Port — Non-Debug Mode

The encoding of data shifted out of the development port shift register when the processor is not in debug mode is shown in **Table 8-14**.

Table 8-14 Status Shifted Out of Shift Register — Non-Debug Mode

Ready	Status [0:1]		Data (7 or 32 Bits[1])	Indication
(0)	0	1	Ones	Sequencing Error
(0)	1	1	Ones	Null

NOTES:
1. Depending on input mode.

When the processor is not in debug mode, the sequencing error encoding indicates that the transmission from the external development tool was a transmission to the CPU (length = 0). When a sequencing error occurs, the development port ignores the data being shifted in while the sequencing error is shifting out.

The null output encoding is used to indicate that the previous transmission did not have any associated errors.

When the processor is not in debug mode, the ready bit is asserted at the end of each transmission. If debug mode is not enabled and transmission errors can be guaranteed not to occur, the status output is not needed, and the DSDO pin can be used for untimed I/O.

8.3.8 Serial Data Out of Development Port — Debug Mode

The encoding of data shifted out of the development port shift register when the processor is in debug mode is shown in **Table 8-14**.

Table 8-15 Status/Data Shifted Out of Shift Register

Ready	Status [0:1]		Data (7 or 32 Bits[1])	Indication
(0)	0	0	Data	Valid Data from CPU
(0)	0	1	Ones	Sequencing Error
(0)	1	0	Ones	CPU Exception
(0)	1	1	Ones	Null

NOTES:
1. Depending on input mode.

8.3.8.1 Valid Data Output

The *valid data* encoding is used when data has been transferred from the CPU to the development port shift register. This is the result of executing an instruction in debug mode to move the contents of a general-purpose register to the development port data register (DPDR).

The valid data encoding has the highest priority of all status outputs and is reported even if an exception occurs at the same time. Any exception that is recognized during the transmission of valid data is not related to the execution of an instruction. Therefore, a status of valid data is output and the CPU exception status is saved for the next transmission. Since it is not possible for a sequencing error to occur and for valid data

to be received on the same transmission, there is no conflict between a valid data status and the sequencing error status.

8.3.8.2 Sequencing Error Output

The *sequencing error* encoding indicates that the inputs from the external development tool are not what the development port or the CPU was expecting. Two cases could cause this error: 1) the processor was trying to read instructions and data was shifted into the development port, or 2) the processor was trying to read data and an instruction was shifted into the development port.

When a sequencing error occurs, the port terminates the CPU read or fetch cycle with a bus error. This bus error causes the CPU to signal the development port that an exception occurred. Since a status of sequencing error has a higher priority than a status of exception, the port reports the sequencing error. The development port ignores the data being shifted in while the sequencing error is shifting out. The next transmission to the port should be a new instruction or trap enable data.

Table 8-16 illustrates a typical sequence of events when a sequencing error occurs. This example begins with CPU data being shifted into the shift register (control bit = 1) when the processor is expecting an instruction. During the next transmission, a sequencing error is shifted out of the development port, and the data shifted into the shift register is thrown away. During the third transmission, the “CPU exception” status is output, and again the data shifted into the shift register is thrown away. During the fourth transmission, an instruction is again shifted into the development port and fetched by the CPU for execution. Notice in this example that the development port throws away the first two input transmissions following the one causing the sequencing error.

Table 8-16 Sequencing Error Activity

Trans #	Input to Development Port	Output from Development Port	Port Action	CPU Action
1	CPU data (Control bit = 1)	Depends on previous transmissions	Cause bus error, set sequence error latch	Fetch instruction, take exception because of bus error
2	X (Thrown away)	Sequencing error	Set exception latch, clear sequencing error latch	Signal exception to port, begin new fetch from port
3	X (Thrown away)	CPU exception	Clear exception latch	Continue to wait for instruction from port
4	CPU instruction	Null	Send instruction to CPU at end of transmission	Fetch instruction from port

8.3.8.3 CPU Exception Output

The *CPU exception* encoding is used to indicate that the CPU encountered an exception during the execution of the previous instruction in debug mode. Exceptions may occur as the result of instruction execution (such as unimplemented opcode or arithmetic error), because of a memory access fault, or from an external interrupt. The exception is recognized only if the associated bit in the DER is set. When an exception occurs, the development port ignores the data being shifted in while the CPU excep-

tion status is shifting out. The port terminates the current CPU access with a bus error. The next transmission to the port should be a new instruction or trap enable data.

8.3.8.4 Null Output

Finally, the *null* encoding is used to indicate that no data has been transferred from the CPU to the development port shift register. It also indicates that the previous transmission did not have any associated errors.

8.3.9 Use of the Ready Bit

To minimize the overhead required to detect and correct errors, the external development system should wait for the ready bit on DSDO before beginning each input transmission. This ensures that all CPU activity (if any) relative to the previous transmission has been completed and that any errors have been reported.

When the ready bit is used to pace the transmissions, the error status is reported during the transmission following the error. Since any transmission into the port which occurs while shifting out an error status is ignored by the port, the error handler in the external development tool does not need to undo the effects of an intervening instruction.

To improve system performance, however, an external development system may begin transmissions before the ready bit is asserted. If the next transmission does not wait until the port indicates ready, the port will not assert ready again until this next transmission completes and all activity associated with it has finished. Transmissions that begin before ready is asserted on DSDI are subject to the following limitations and problems.

First, if the previous transmission results in a sequence error, or the CPU reports an exception, that status may not be reported until two transmissions after the transmission that caused the error. (When the ready bit is used, the status is reported in the following transmission.) This is because an error condition which occurs after the start of a transmission cannot be reported until the next transmission.

Second, if a transmitted instruction causes the CPU to write to the DPDR and the transmission that follows does not wait for the assertion of ready, the CPU data may not be latched into the development port shift register, and the valid data status is not output. Despite this, no error is indicated in the status outputs. To ensure that the CPU has had enough time to write to the DPDR, there must be at least four CLKOUT cycles between the time the last bit of the instruction (move to SPR) is clocked into the port and the time the start bit for the next transmission is clocked into the port.

8.4 Debug Mode Functions

In debug mode, the CPU fetches all instructions from the development port. In addition, data can be read from and written to the development port. This allows memory and registers to be read and modified by an external development tool (emulator) connected to the development port.

8.4.1 Enabling Debug Mode

Debug mode is enabled by asserting the DSCK pin during reset. The state of this pin is sampled immediately before the negation of RESETOUT. If the DSCK pin is sampled low, debug mode is disabled until a subsequent reset when the DSCK pin is sampled high. When debug mode is disabled, the internal watchpoint/breakpoint hardware is still operational and can be used by a software monitor program for debugging purposes.

The DSCK pin is sampled again eight clock cycles following the negation of RESETOUT. If DSCK is negated following reset, the processor jumps to the reset vector and begins normal execution. If DSCK is asserted following reset and debug mode is enabled, the processor enters debug mode before executing any instructions.

A timing diagram for enabling debug mode is shown in **Figure 8-11**.

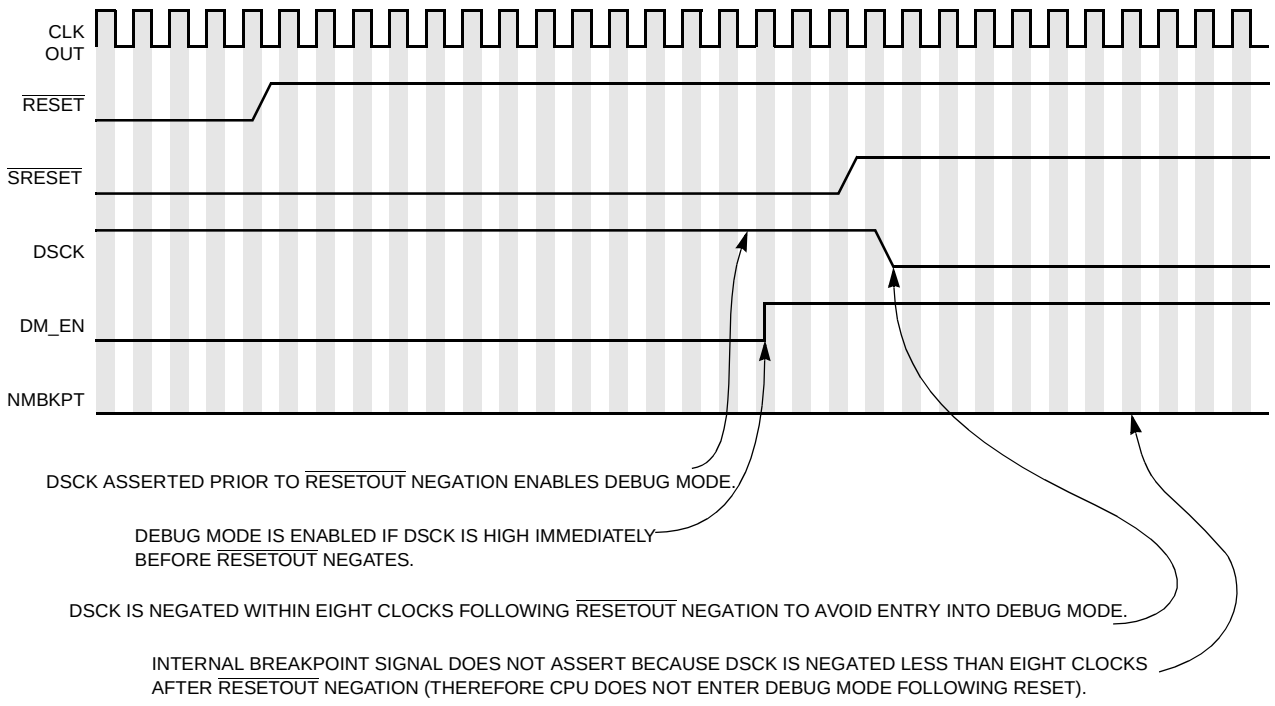

CLK OUT
RESET
SRESET
DSCK
DM_EN
NMBKPT
DSCK ASSERTED PRIOR TO RESETOUT NEGATION ENABLES DEBUG MODE.
DEBUG MODE IS ENABLED IF DSCK IS HIGH IMMEDIATELY BEFORE RESETOUT NEGATES.
DSCK IS NEGATED WITHIN EIGHT CLOCKS FOLLOWING RESETOUT NEGATION TO AVOID ENTRY INTO DEBUG MODE.
INTERNAL BREAKPOINT SIGNAL DOES NOT ASSERT BECAUSE DSCK IS NEGATED LESS THAN EIGHT CLOCKS AFTER RESETOUT NEGATION (THEREFORE CPU DOES NOT ENTER DEBUG MODE FOLLOWING RESET).

Figure 8-11 Enabling Debug Mode at Reset

8.4.2 Entering Debug Mode

Debug mode is entered whenever debug mode is enabled, an exception occurs, and the corresponding bit is set in the debug enable register (DER). The processor performs normal exception processing, i.e., saving the next instruction address and the current state of MSR in SRR0 and SRR1 and modifying the contents of the MSR. The processor then enters debug mode and fetches the next instruction from the development port instead of from the vector address. The exception cause register (ECR) shows which event caused entry into debug mode. The freeze indication is encoded on the VFLS pins to show that the CPU is in debug mode.

Debug mode may also be entered immediately following reset. If the DSCK pin continues to be asserted following reset (after debug mode is enabled), the processor takes a breakpoint exception and enters debug mode directly after fetching (but not executing) the reset vector. To avoid entering debug mode following reset, the DSCK pin must be negated no later than seven clock cycles after RESETOUT is negated.

A timing diagram for entering debug mode following reset is shown in **Figure 8-12**.

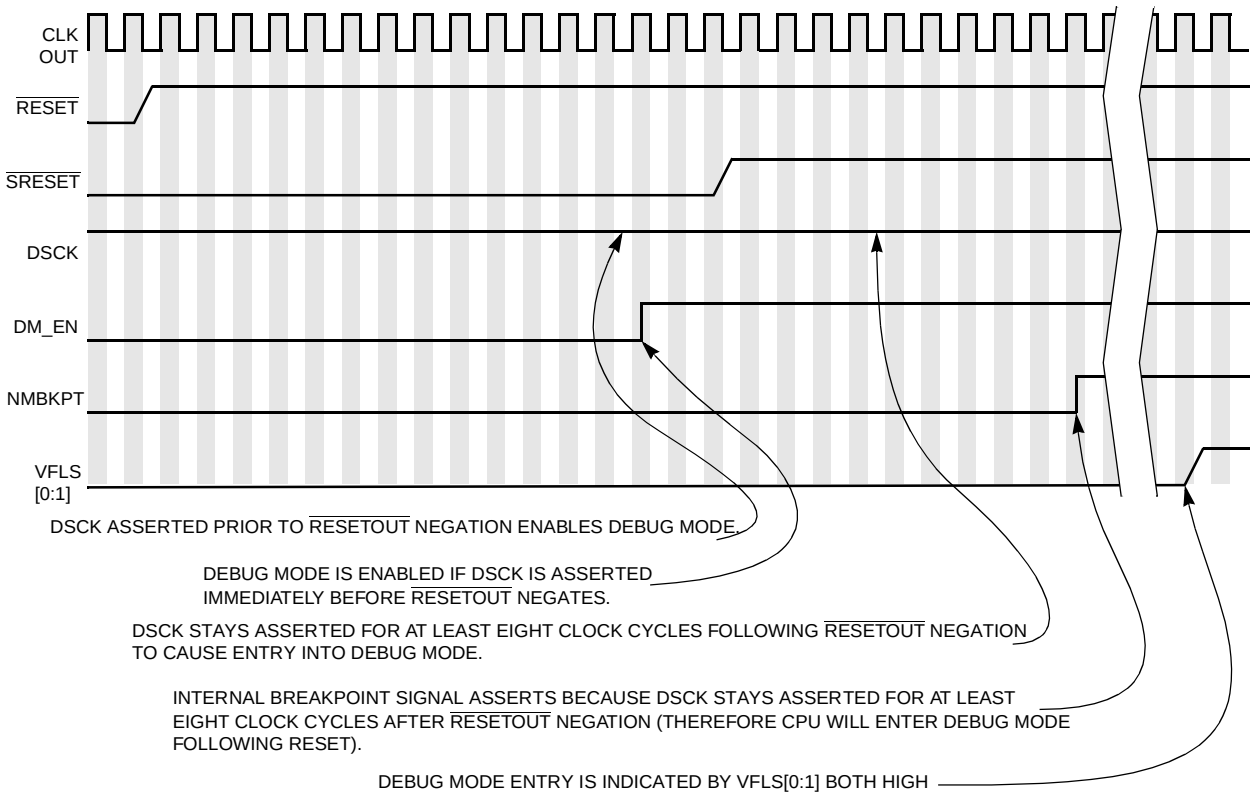

CLK OUT
RESET
SRESET
DSCK
DM_EN
NMBKPT
VFLS [0:1]
DSCK ASSERTED PRIOR TO RESETOUT NEGATION ENABLES DEBUG MODE.
DEBUG MODE IS ENABLED IF DSCK IS ASSERTED IMMEDIATELY BEFORE RESETOUT NEGATES.
DSCK STAYS ASSERTED FOR AT LEAST EIGHT CLOCK CYCLES FOLLOWING RESETOUT NEGATION TO CAUSE ENTRY INTO DEBUG MODE.
INTERNAL BREAKPOINT SIGNAL ASSERTS BECAUSE DSCK STAYS ASSERTED FOR AT LEAST EIGHT CLOCK CYCLES AFTER RESETOUT NEGATION (THEREFORE CPU WILL ENTER DEBUG MODE FOLLOWING RESET).
DEBUG MODE ENTRY IS INDICATED BY VFLS[0:1] BOTH HIGH

Figure 8-12 Entering Debug Mode Following Reset

8.4.3 Debug Mode Operation

In debug mode, the CPU fetches instructions from the development port. It can also read and write data at the development port. In debug mode the prefetch mechanism in the CPU is disabled. This forces all data accesses to the development port to occur immediately following the fetch of the associated instruction.

In debug mode, if an exception occurs during the execution of an instruction, normal exception processing does not result. (That is, the processor does not save the MSR and instruction address and does not branch to the exception handler.) Instead, a flag is set that results in a CPU exception status indication in the data shifted out of the development port shift register. The same thing happens if the processor detects an external interrupt. (This can occur only when the associated DER bit is clear and MSR[EE] is set.) When the data in the development port shift register is shifted out,

the exception status is detected by the external development tool. The cause of the exception can be determined by reading the ECR.

8.4.4 Freeze Function

While the processor is in debug mode, the freeze indication is broadcast throughout the MCU. This signal is generated by the CPU when debug mode is entered, or when a software debug monitor program is entered as the result of an exception and the associated bit in the DER is set. The software monitor can only assert freeze when debug mode is not enabled. Refer to 8.7 Software Monitor Support for more information.

Freeze is indicated by the value 11 on the VFLS[0:1] pins. This encoding is not used for pipeline tracking and is left on the VFLS[0:1] pins when the processor is in debug mode. **Figure 8-14** shows how the internal freeze signal is generated.

8.4.5 Exiting Debug Mode

Executing the **rfi** instruction in debug mode causes the processor to leave debug mode and return to normal execution. The freeze indication on the VFLS pins is negated to indicate that the CPU has exited debug mode.

Software must read the ECR (to clear it) before executing the **rfi** instruction. Otherwise, if a bit in the ECR is asserted and its corresponding enable bit in the DER is also asserted, the processor re-enters debug mode and re-asserts the freeze signal immediately after executing the **rfi** instruction.

8.4.6 Checkstop State and Debug Mode

When debug mode is disabled, the processor enters the checkstop state if, when a machine check exception is detected, the machine check exception is disabled (MSR[ME] = 0). However, when debug mode is enabled, if a machine check exception is detected when MSR[ME] = 0 and the checkstop enable bit in the DER is set, the processor enters debug mode rather than the checkstop state. This allows the user to determine why the checkstop state was entered. **Table 8-17** shows what happens when a machine check exception occurs under various conditions.

Table 8-17 Checkstop State and Debug Mode

MSR[ME]	Debug Mode Enable	CHSTPE[1]	MCIE[2]	Action Performed when CPU Detects a Machine Check Interrupt	ECR Value
0	0	X	X	Enter the checkstop state	0x2000 0000
0	1	0	X	Enter the checkstop state	0x2000 0000
0	1	1	X	Enter debug mode	0x2000 0000
1	0	X	X	Take machine check exception	0x1000 0000
1	1	X	0	Take machine check exception	0x1000 0000
1	1	X	1	Enter debug mode	0x1000 0000

NOTES:
1. Checkstop enable bit in the DER
2. Machine check interrupt enable bit in the DER

8.5 Development Port Transmission Sequence

The following sections describe the sequence of events for communication with the development port in both debug and normal mode and provide specific sequences for prologues, epilogues, and poking and peeking operations.

8.5.1 Port Usage in Debug Mode

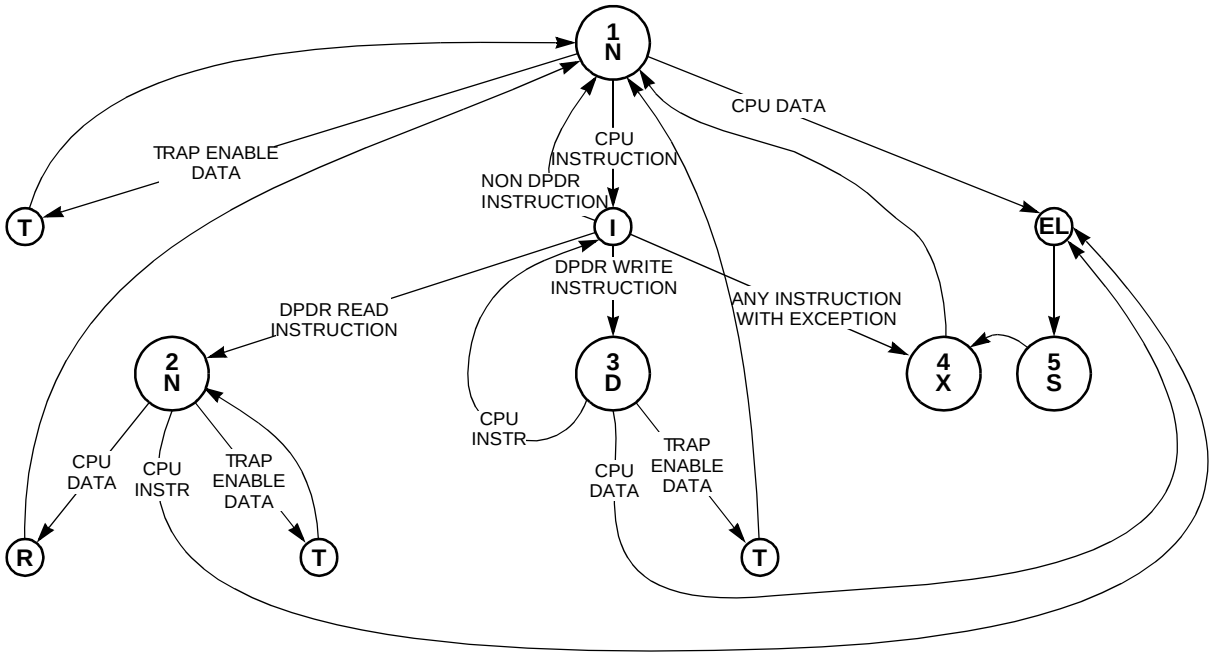
The sequence of events for communication with the development port in debug mode (freeze is indicated on the VFLS pins) is shown in **Table 8-18**. The sequence starts with the processor trying to read an instruction in step 1. The sequence ends when the processor is ready to read the next instruction. Reading an instruction is the first action the processor takes after entering debug mode. The processor and development port activity is determined by the instruction or data shifted into the shift register. The instruction or data shifted into the shift register also determines the status shifted out during the next transmission. The next step column indicates which step has the appropriate status response.

Table 8-18 Debug Mode Development Port Usage

This Step	Serial Data Shifted In (DSDO Indicates "READY")	Shifted Out This Transmission	Development Port Activity; Processor Activity	Next Step
1	CPU instruction (non-DPDR)	Null	Port transfers instruction to CPU; CPU executes instruction, fetches next instruction	1
	CPU instruction (DPDR read)		Port transfers instruction to CPU; CPU executes instruction, reads DPDR	2
	CPU instruction (DPDR write)		Port transfers instruction to CPU; CPU writes DPDR, fetches next instruction	3
	CPU instruction (instruction execution causes exception)		Port transfers instruction to CPU; CPU signals exception to port, fetches next instruction	4
	Data for CPU		Port ignores data, terminates fetch with error, latches sequence error; CPU signals exception to port, fetches next instruction	5
	Data for Trap Enable Control Register		Port updates trap enable control register; CPU waits (continues fetch)	1
2	Any CPU instruction	Null	Port ignores data, terminates DPDR read with error; latches sequence error; CPU signals exception to port, fetches next instruction	5
	Data for CPU		Port transfers data to CPU; CPU reads data from DPDR, fetches next instruction	1
	Data for trap enable control register		Port updates TECR CPU waits (continue data read)	2
3	CPU instruction (non-DPDR)	CPU data	Port transfers instruction to CPU; CPU executes instruction, fetches next instruction	1
	CPU instruction (DPDR read)		Port transfers instruction to CPU; CPU executes instruction, reads DPDR	2
	CPU instruction (DPDR write)		Port transfers instruction to CPU; CPU writes DPDR, fetches next instruction	3
	CPU instruction (with exception)		Port transfers instruction to CPU; CPU signals exception to port, fetches next instruction	4
	Data for CPU		Port ignores data, terminates fetch with error, latches sequence error; CPU signals exception to port, fetches next instruction	5
	Data for trap enable control register	7 MSB of CPU data	Port updates TECR; CPU waits (continues fetch)	1
4	Any (ignored by port)	Exception	Port ignores data; CPU waits (continues fetch)	1
5	Any (ignored by port)	Sequence Error	Port ignores data; CPU waits (continues fetch)	4

8.5.2 Debug Mode Sequence Diagram

The sequence of activity shown in **Table 8-18** is summarized below in **Figure 8-13**. The numbers in the large circles correspond to the steps in **Table 8-18**. The letters in the large circles indicate the status that will be shifted out during the transmission. The letters in the small circles show the activity of the development port and the CPU as a result of the transmission.



N - SHIFT OUT NULL STATUS
X - SHIFT OUT EXCEPTION STATUS
S - SHIFT OUT SEQUENCE ERROR STATUS
D - SHIFT OUT DATA FROM CPU
E - TERMINATE CPU READ WITH ERROR
L - LATCH SEQUENCE ERROR
I - TRANSFER INSTR TO CPU
R - TRANSFER DATA TO CPU (READ)
T - TRANSFER DATA TO TECR

Figure 8-13 General Port Usage Sequence Diagram

8.5.3 Port Usage in Normal (Non-Debug) Mode

The sequence of events for communication with the development port when the CPU is not in debug mode (freeze is not indicated on the VFLS pins) is shown below in **Table 8-18**. Note that any instructions or data for the CPU result in a sequence error status response when the processor is not in debug mode. Only data for the trap enable control register is allowed.

Table 8-19 Non-Debug Mode Development Port Usage

This Step	Serial Data Shifted into DPDI (Not in Debug Mode)	Shifted out of DPDO this Transmission	Development Port Activity	Next Step
6	Any CPU instruction or data	Null	Port ignores data and latches sequence error	7
	Data for trap enable control register		Port updates trap enable control register	6
7	Any (ignored by port)	Sequence Error	Port ignores data	6

8.6 Examples of Debug Mode Sequences

The tables that follow show typical sequences of instructions that are used in a development activity. They assume that no bus errors or sequence errors occur and that no writes occur to the trap enable control register.

8.6.1 Prologue Instruction Sequence

The prologue sequence of instructions is used to unload the machine context when entering debug mode. The sequence starts by unloading two general-purpose registers (R0 and R1) to be used as a data transfer register and an address pointer. Since SRR0 and SRR1 are not changed while in debug mode except by explicitly writing to them, there is no need to save and restore these registers. Finally, the ECR is unloaded to determine the cause of entry into debug mode. Any registers that will be used while in debug mode in addition to R0 and R1 will also need to be saved.

Table 8-20 Prologue Events

Development Port Activity	Instruction	Processor Activity	Purpose
Shift in instruction	**mtspr** DPDR, R0	Transfer R0 to DPDR	Save R0 so the register can be used
Shift out R0 data, shift in instruction	**mfspr** R0, ECR	Transfer ECR to R0	Read the debug mode cause register
Shift in instruction	**mtspr** DPDR, R0	Transfer from R0 to DPDR	Output reason for debug mode entry
Shift out stop cause data, shift in instruction	**mtspr** DPDR, R1	Transfer R1 to DPDR	Save R1 so the register can be used
Shift out R1 data, shift in instruction	First instruction of next sequence	Execute next instruction	Continue instruction processing

8.6.2 Epilogue Instruction Sequence

The epilogue sequence of instructions is used to restore the machine context when leaving debug mode. It restores the two general-purpose registers and then issues the **rfi** instruction. If additional registers were used while in debug mode, they also need to be restored before the **rfi** instruction is executed.

Table 8-21 Epilogue Events

Development Port Activity	Instruction	Processor Activity	Purpose
Shift in instruction, shift in saved R0	**mfspr** R0, DPDR	Transfer from DPDR to R0	Restores value of R0 when stopped
Shift in instruction, shift in saved R1	**mfspr** R1, DPDR	Transfer from DPDR to R1	Restores value of R1 when stopped
Shift in instruction	**rfi**	Return from exception	Restart execution

8.6.3 Peek Instruction Sequence

The peek sequence of instructions is used to read a memory location and transfer the data to the development port. It starts by moving the memory address into R1 from the development port. Next the location is read and the data loaded into R0. Finally, R0 is transferred to the development port.

Table 8-22 Peek Instruction Sequence

Development Port Activity	Instruction	Processor Activity	Purpose
Shift in instruction	**mfspr** R1, DPDR	Transfer address from DPDR to R1	Point to memory address
Shift in instruction	**lwzu** R0, D(R1)	Load data from memory address (R1) into R0	Read data from memory
Shift in instruction	**mtspr** DPDR, R0	Transfer data from R0 to DPDR	Write memory data to the port
Shift in instruction, shift out memory data	First instruction of next sequence	Execute next instruction	Output memory data

8.6.4 Poke Instruction Sequence

The poke sequence of instructions is used to write data entered at the development serial port to a memory location. It starts by moving the memory address into R1 from the development port. Next the data is moved into R0 from the development port. Finally, R0 is written to the address in R1.

Table 8-23 Poke Instruction Sequence

Development Port Activity	Instruction	Processor Activity	Purpose
Shift in instruction	**mfspr** R1, DPDR	Transfer address from DPDR to R1	Point to memory address
Shift in instruction, shift in memory data	**mfspr** R0, DPDR	Transfer data from DPDR to R0	Read memory data from the port
Shift in instruction	**stwu** R0, D(R1)	Store data from R0 to memory address (R1)	Write data to memory

8.7 Software Monitor Support

When debug mode is disabled, a software monitor debugger can make use of all of the processor's development support features. With debug mode disabled, all events result in regular exception handling, i.e., the processor resumes execution in the

appropriate exception handler. The ECR and the DER only influence the assertion and negation of the freeze indication.

The internal freeze signal is connected to all relevant internal modules. These modules can be programmed to stop all operations in response to the assertion of the freeze signal. In order to enable a software monitor debugger to broadcast the fact that the debug software is now executing, it is possible to assert and negate the internal freeze signal when debug mode is disabled. (The freeze signal can be asserted externally only when the processor enters debug mode.)

The internal freeze signal is asserted whenever an enabled event occurs, regardless of whether debug mode is enabled or disabled. To enable an event to cause freeze assertion, software needs to set the relevant bit in the DER. To clear the freeze signal, software needs to read the ECR to clear the register and then perform an **rfi** instruction.

If the ECR is not cleared before the **rfi** instruction is executed, freeze is not negated. It is therefore possible to nest inside a software monitor debugger without affecting the value of the freeze signal, even though **rfi** is performed. Only before the last **rfi** does the software need to clear the ECR.

Figure 8-14 shows how the ECR and DER control the assertion and negation of the freeze signal and the internal debug mode signal.

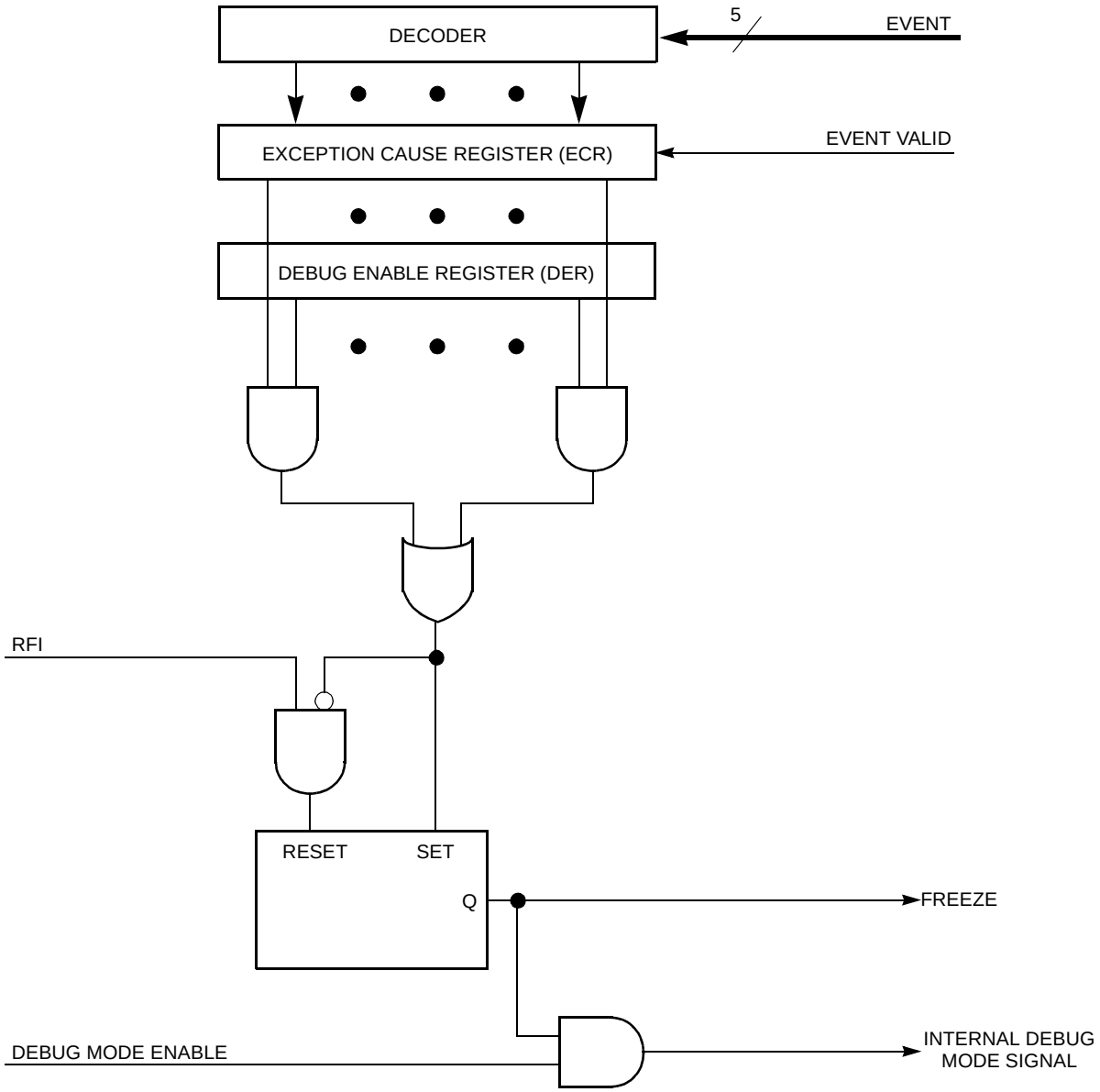


Figure 8-14 Debug Mode Logic

8.8 Development Support Registers

Table 8-24 lists the registers used for development support. The registers are accessed with the **mtspr** and **mfspr** instructions.

Table 8-24 Development Support Programming Model

SPR Number (Decimal)	Mnemonic	Name
144	CMPA	Comparator A Value Register
145	CMPB	Comparator B Value Register
146	CMPC	Comparator C Value Register
147	CMPD	Comparator D Value Register
148	ECR	Exception Cause Register
149	DER	Debug Enable Register
150	COUNTA	Breakpoint Counter A Value and Control Register
151	COUNTB	Breakpoint Counter B Value and Control Register
152	CMPE	Comparator E Value Register
153	CMPF	Comparator F Value Register
154	CMPG	Comparator G Value Register
155	CMPH	Comparator H Value Register
156	LCTRL1	L-Bus Support Control Register 1
157	LCTRL2	L-Bus Support Control Register 2
158	ICTRL	I-Bus Support Control Register
159	BAR	Breakpoint Address Register
630	DPDR	Development Port Data Register

8.8.1 Register Protection

Table 8-25 and **Table 8-26** summarize protection features of development support registers during read and write accesses, respectively.

Table 8-25 Development Support Registers Read Access Protection

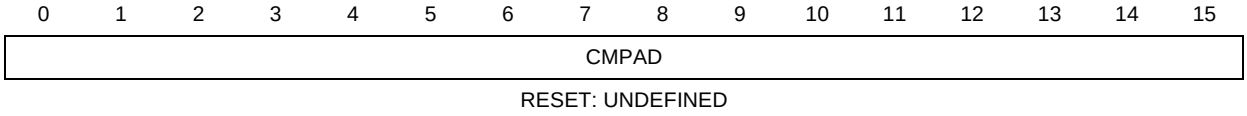
MSR[PR]	Debug Mode Enable	In Debug Mode	Result
0	0	X	Read is performed. ECR is cleared when read. Reading DPDR yields indeterminate data.
0	1	0	Read is performed. ECR is *not* cleared when read. Reading DPDR yields indeterminate data.
0	1	1	Read is performed. ECR is cleared when read.
1	X	X	Program exception is generated. Read is not performed. ECR is *not* cleared when read.

Table 8-26 Development Support Registers Write Access Protection

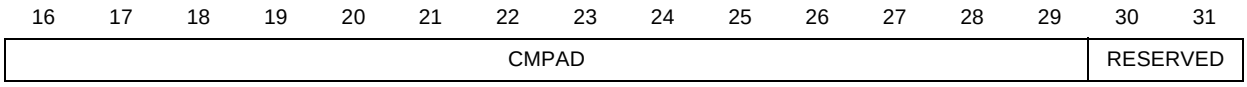
MSR[PR]	Debug Mode Enable	In Debug Mode	Result
0	0	X	Write is performed. Write to ECR is ignored. Writing to DPDR is ignored.
0	1	0	Write is *not* performed. Writing to DPDR is ignored.
0	1	1	Write is performed. Write to ECR is ignored.
1	X	X	Write is *not* performed. Program exception is generated.

8.8.2 Comparator A–D Value Registers (CMPA–CMPD)

CMPA–CMPD — Comparator A–D Value Register **SPR 144 – SPR 147**



RESET: UNDEFINED



RESET: UNDEFINED

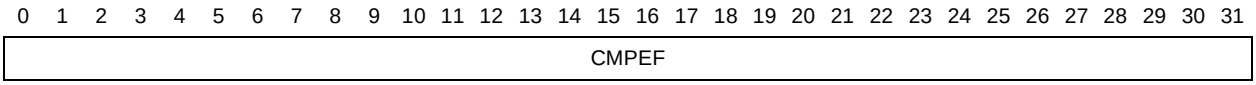
Table 8-27 CMPA–CMPD Bit Settings

Bits	Mnemonic	Description
0:29	CMPAD	Address bits to be compared
30:31	—	Reserved

The reset state of these registers is undefined.

8.8.3 Comparator E–F Value Registers

CMPE–CMPF — Comparator E–F Value Registers **SPR 152, 153**



RESET: UNDEFINED

Table 8-28 CMPE–CMPF Bit Settings

Bits	Mnemonic	Description
0:31	CMPV	Address bits to be compared

The reset state of these registers is undefined.

8.8.4 Comparator G–H Value Registers (CMPG–CMPH)

CMPG–CMPH — Comparator G–H Value Registers **SPR 154, 155**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CMPGH																															
RESET: UNDEFINED																															

Table 8-29 CMPG–CMPH Bit Settings

Bits	Mnemonic	Description
0:31	CMPGH	Data bits to be compared

The reset state of these registers is undefined.

8.8.5 I-Bus Support Control Register

ICTRL — I-Bus Support Control Register **SPR 158**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CTA			CTB			CTC			CTD			IW0		IW1	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
IW2		IW3		SIW0 EN	SIW1 EN	SIW2 EN	SIW3 EN	DIW0 EN	DIW1 EN	DIW2 EN	DIW3 EN	IIFM	ISCT_SER		
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-30 ICTRL Bit Settings

Bits	Mnemonic	Description	Function
0:2	CTA	Compare type of comparator A	0xx - not active (reset value) 100 - equal 101 - less than 110 - greater than 111 - not equal
3:5	CTB	Compare type of comparator B	
6:8	CTC	Compare type of comparator C	
9:11	CTD	Compare type of comparator D	
12:13	IW0	I-bus 1st watchpoint programming	0x - not active (reset value) 10 - match from comparator A 11 - match from comparators (A&B)
14:15	W1	I-bus 2nd watchpoint programming	0x - not active (reset value) 10 - match from comparator B 11 - match from comparators (A | B)
16:17	IW2	I-bus 3rd watchpoint programming	0x - not active (reset value) 10 - match from comparator C 11 - match from comparators (C&D)
18:19	IW3	I-bus 4th watchpoint programming	0x - not active (reset value) 10 - match from comparator D 11 - match from comparators (C | D)
20	SIW0EN	Software trap enable selection of the 1st I-bus watchpoint	0 - trap disabled (reset value) 1 - trap enabled
21	SIW1EN	Software trap enable selection of the 2nd I-bus watchpoint	
22	SIW2EN	Software trap enable selection of the 3rd I-bus watchpoint	
23	SIW3EN	Software trap enable selection of the 4th I-bus watchpoint	
24	DIW0EN	Development port trap enable selection of the 1st I-bus watchpoint (read only bit)	0 - trap disabled (reset value) 1 - trap enabled
25	DIW1EN	Development port trap enable selection of the 2nd I-bus watchpoint (read only bit)	
26	DIW2EN	Development port trap enable selection of the 3rd I-bus watchpoint (read only bit)	
27	DIW3EN	Development port trap enable selection of the 4th I-bus watchpoint (read only bit)	

Table 8-30 ICTRL Bit Settings (Continued)

Bits	Mnemonic	Description	Function
28	IIFM	Ignore first match, only for I-bus breakpoints	0 - Do not ignore first match, used for “go to x” (reset value) 1 - Ignore first match (used for “continue”)
29:31	ISCT_SER	Instruction fetch show cycle and RCPU serialize control	000 - RCPU is fully serialized and show cycle will be performed for all fetched instructions (reset value). 001 - RCPU is fully serialized and show cycle will be performed for all changes in the program flow 010 - RCPU is fully serialized and show cycle will be performed for all indirect changes in the program flow 011 - RCPU is fully serialized and no show cycles will be performed for fetched instructions 100 - Illegal 101 - RCPU is not serialized (normal mode) and show cycle will be performed for all changes in the program flow 110 - RCPU is not serialized (normal mode) and show cycle will be performed for all indirect changes in the program flow 111 - RCPU is not serialized (normal mode) and no show cycles will be performed for fetched instructions

The ICTRL is cleared following reset. Note that the machine is fetch serialized whenever SER = 0b0 or ISCTL = 0b00.

8.8.6 L-Bus Support Control Register 1

LCTRL1 — L-Bus Support Control Register 1 **SPR 156**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CTE			CTF			CTG			CTH			CRWE		CRWF	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CSG		CSH		SUSG	SUSH	CGBMSK				CHBMSK				UNUSED	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-31 LCTRL1 Bit Settings

Bits	Mnemonic	Description	Function
0:2	CTE	Compare type, comparator E	0xx - not active (reset value) 100 - equal 101 - less than 110 - greater than 111 - not equal
3:5	CTF	Compare type, comparator F	
6:8	CTG	Compare type, comparator G	
9:11	CTH	Compare type, comparator H	
12:13	CRWE	Select match on read/write of comparator E	0X - don't care (reset value) 10 - match on read 11 - match on write
14:15	CRWF	Select match on read/write of comparator F	
16:17	CSG	Compare size, comparator G	00 - reserved 01 - word 10 - half word 11 - byte (Must be programmed to word for floating point compares)
18:19	CSH	Compare size, comparator H	
20	SUSG	Signed/unsigned operating mode for comparator G	0 - unsigned 1 - signed (Must be programmed to signed for floating point compares)
21	SUSH	Signed/unsigned operating mode for comparator H	
22:25	CGBMSK	Byte mask for 1st L-data comparator	0000 - all bytes are **not** masked 0001 - the last byte of the word is masked . . . 1111 - all bytes are masked
26:29	CHBMSK	Byte mask for 2nd L-data comparator	
30:31	—	Reserved	—

LCTRL1 is cleared following reset.

8.8.7 L-Bus Support Control Register 2

LCTRL2 — L-Bus Support Control Register 2 **SPR 157**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LW0EN	LW0IA		LW0 IADC	LW0LA		LW0 LADC	LW0LD		LW0 LDDC	LW1EN	LW1IA		LW1 IADC	LW1LA	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
LW1 LADC	LW1LD		LW1 LDDC	BRK NOM-SK	RESERVED							DLW0 EN	DLW1 EN	SLW0 EN	SLW1 EN
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-32 LCTRL2 Bit Settings

Bits	Mnemonic	Description	Function
0	LW0EN	1st L-bus watchpoint enable bit	0 - watchpoint not enabled (reset value) 1 - watchpoint enabled
1:2	LW0IA	1st L-bus watchpoint I-addr watchpoint selection	00 - first I-bus watchpoint 01 - second I-bus watchpoint 10 - third I-bus watchpoint 11 - fourth I-bus watchpoint
3	LW0IADC	1st L-bus watchpoint care/don't care I-addr events	0 - don't care 1 - care
4:5	LW0LA	1st L-bus watchpoint L-addr events selection	00 - match from comparator E 01 - match from comparator F 10 - match from comparators (E&F) 11 - match from comparators (E | F)
6	LW0LADC	1st L-bus watchpoint care/don't care L-addr events	0 - don't care 1 - care
7:8	LW0LD	1st L-bus watchpoint L-data events selection	00 - match from comparator G 01 - match from comparator H 10 - match from comparators (G&H) 11 - match from comparators (G | H)
9	LW0LDDC	1st L-bus watchpoint care/don't care L-data events	0 - don't care 1 - care
10	LW1EN	2nd L-bus watchpoint enable bit	0 - watchpoint not enabled (reset value) 1 - watchpoint enabled
11:12	LW1IA	2nd L-bus watchpoint I-addr watchpoint selection	00 - first I-bus watchpoint 01 - second I-bus watchpoint 10 - third I-bus watchpoint 11 - fourth I-bus watchpoint
13	LW1IADC	2nd L-bus watchpoint care/don't care I-addr events	0 - don't care 1 - care
14:15	LW1LA	2nd L-bus watchpoint L-addr events selection	00 - match from comparator E 01 - match from comparator F 10 - match from comparators (E&F) 11 - match from comparators (E | F)
16	LW1LADC	2nd L-bus watchpoint care/don't care L-addr events	0 - don't care 1 - care
17:18	LW1LD	2nd L-bus watchpoint L-data events selection	00 - match from comparator G 01 - match from comparator H 10 - match from comparators (G&H) 11 - match from comparator (G | H)
19	LW1LDDC	2nd L-bus watchpoint care/don't care L-data events	0 - don't care 1 - care
20	BRKNOMSK	Internal breakpoints non-mask bit	0 - masked mode; breakpoints are recognized only when MSR[RI] = 1 (reset value) 1 - non-masked mode; breakpoints are always recognized
21:27	—	Reserved	—

Table 8-32 LCTRL2 Bit Settings (Continued)

Bits	Mnemonic	Description	Function
28	DLW0EN	Development port trap enable selection of the 1st L-bus watchpoint (read only bit)	0 - trap disabled (reset value) 1 - trap enabled
29	DLW1EN	Development port trap enable selection of the 2nd L-bus watchpoint (read only bit)	
30	SLW0EN	Software trap enable selection of the 1st L-bus watchpoint	
31	SLW1EN	Software trap enable selection of the 2nd L-bus watchpoint	

LCTRL2 is cleared following reset.

For each watchpoint, three control register fields (LWxIA, LWxLA, LWxLD) must be programmed. For a watchpoint to be asserted, all three conditions must be detected.

8.8.8 Breakpoint Counter A Value and Control Register

COUNTA — Breakpoint Counter A Value and Control Register **SPR 150**

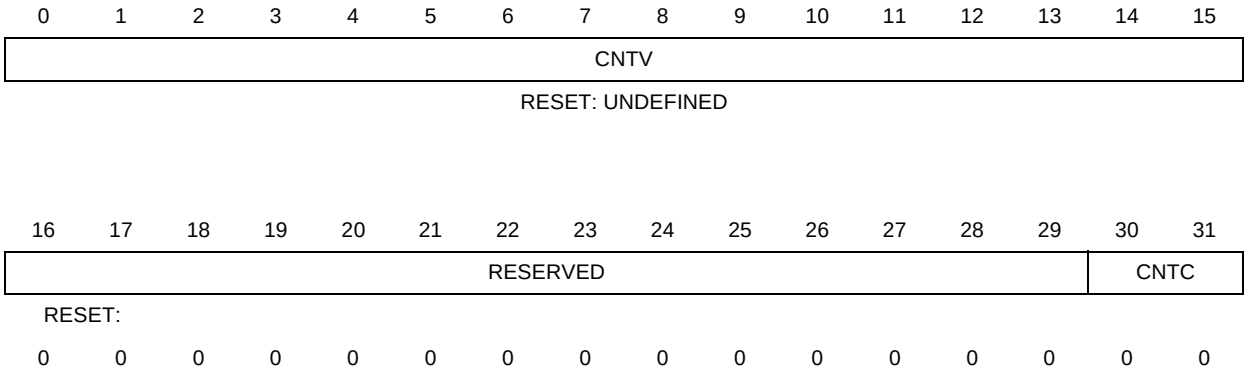


Table 8-33 Breakpoint Counter A Value and Control Register (COUNTA)

Bit(s)	Name	Description
0:15	CNTV	Counter preset value
16:29	—	Reserved
30:31	CNTC	Counter source select 00 - not active (reset value) 01 - I-bus first watchpoint 10 - L-bus first watchpoint 11 - Reserved

COUNTA[16:31] are cleared following reset; COUNTA[0:15] are undefined.

8.8.9 Breakpoint Counter B Value and Control Register

COUNTB — Breakpoint Counter B Value and Control Register **SPR 151**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CNTV															

RESET: UNDEFINED

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
RESERVED														CNTC	
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-34 Breakpoint Counter B Value and Control Register (COUNTB)

Bit(s)	Name	Description
0:15	CNTV	Counter preset value
16:29	—	Reserved
30:31	CNTC	Counter source select 00 - not active (reset value) 01 - I-bus second watchpoint 10 - L-bus second watchpoint 11 - Reserved

COUNTB[16:31] are cleared following reset; COUNTB[0:15] are undefined.

8.8.10 Exception Cause Register (ECR)

The ECR indicates the cause of entry into debug mode. All bits are set by the hardware and cleared when the register is read when debug mode is disabled, or if the processor is in debug mode. Attempts to write to this register are ignored. When the hardware sets a bit in this register, debug mode is entered only if debug mode is enabled and the corresponding mask bit in the DER is set.

All bits are cleared to zero following reset.

ECR — Exception Cause Register **SPR 148**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED		CHSTP	MCE	DSE	ISE	EXTI	ALE	PRE	FPUVE	DECE	RESERVED		SYSE	TR	FPASE
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	SEE	RESERVED										LBRK	IBRK	EBRKD	DPI
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-35 ECR Bit Settings

Bit(s)	Name	Description
0:1	—	Reserved
2	CHSTP	Checkstop bit. Set when the processor enters checkstop state.
3	MCE	Machine check interrupt bit. Set when a machine check exception (other than one caused by a data storage or instruction storage error) is asserted.
4	DSE	Data storage exception bit. Set when a machine check exception caused by a data storage error is asserted.
5	ISE	Instruction storage exception bit. Set when a machine check exception caused by an instruction storage error is asserted.
6	EXTI	External interrupt bit. Set when the external interrupt is asserted.
7	ALE	Alignment exception bit. Set when the alignment exception is asserted.
8	PRE	Program exception bit. Set when the program exception is asserted.
9	FPUVE	Floating point unavailable exception bit. Set when the program exception is asserted.
10	DECE	Decrementer exception bit. Set when the decrementer exception is asserted.
11:12	—	Reserved
13	SYSE	System call exception bit. Set when the system call exception is asserted.
14	TR	Trace exception bit. Set when in single-step mode or when in branch trace mode.
15	FPASE	Floating point assist exception bit. Set when the floating-point assist exception is asserted.
16	—	Reserved
17	SEE	Software emulation exception. Set when the software emulation exception is asserted.
18:27		Reserved
28	LBRK	L-bus breakpoint exception bit. Set when an L-bus breakpoint is asserted.
29	IBRK	I-bus breakpoint exception bit. Set when an I-bus breakpoint is asserted.
30	EBRK	External breakpoint exception bit. Set when an external breakpoint is asserted (by an on-chip IMB or L-bus module, or by an external device or development system through the development port).
31	DPI	Development port interrupt bit. Set by the development port as a result of a debug station non-maskable request or when debug mode is entered immediately out of reset.

8.8.11 Debug Enable Register (DER)

This register enables the user to selectively mask the events that may cause the processor to enter into debug mode.

DER — Debug Enable Register **SPR 149**

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RESERVED		CHSTPE	MCEE	DSEE	ISEE	EXTIE	ALEE	PREE	FPUVEE	DECEE	RESERVED		SYSEE	TRE	FPASEE
RESET:															
0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	SEEE	RESERVED										LBRKE	IBRKE	EBRKE	DPIE
RESET:															
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

Table 8-36 DER Bit Settings

Bit(s)	Name	Description
0:1	—	Reserved
2	CHSTPE	Checkstop enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)
3	MCEE	Machine check exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
4	DSEE	Data storage exception (type of machine check exception) enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
5	ISEE	Instruction storage exception (type of machine check exception) enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
6	EXTIE	External interrupt enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
7	ALEE	Alignment exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
8	PREE	Program exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
9	FPUVEE	Floating point unavailable exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
10	DECEE	Decrementer exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
11:12	—	Reserved

Table 8-36 DER Bit Settings (Continued)

Bit(s)	Name	Description
13	SYSEE	System call exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
14	TRE	Trace exception enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)
15	FPASEE	Floating point assist exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
16	—	Reserved
17	SEEE	Software emulation exception enable bit 0 = Debug mode entry disabled (reset value) 1 = Debug mode entry enabled
18:27	—	Reserved
28	LBRKE	L-bus breakpoint exception enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)
29	IBRKE	I-bus breakpoint exception enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)
30	EBRKE	External breakpoint exception enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)
31	DPIE	Development port interrupt enable bit 0 = Debug mode entry disabled 1 = Debug mode entry enabled (reset value)

SECTION 9
IEEE 1149.1-COMPLIANT INTERFACE

The MPC509 includes dedicated user-accessible test logic that is fully compatible with the *IEEE 1149.1-1990 Standard Test Access Port and Boundary Scan Architecture*. Problems associated with testing high-density circuit boards have led to development of this standard under the sponsorship of the Test Technology Committee of IEEE and the Joint Test Action Group (JTAG). The MPC509 supports circuit-board test strategies based on this standard.

This section is intended to be used with the supporting IEEE 1149.1-1990 standard. The scope of this description includes those items required by the standard to be defined and, in certain cases, provides additional information specific to the implementation. For internal details and applications of the standard, refer to the IEEE 1149.1-1990 document.

An overview of the JTAG pins on the MPC509 is shown in **Figure 9-1**.

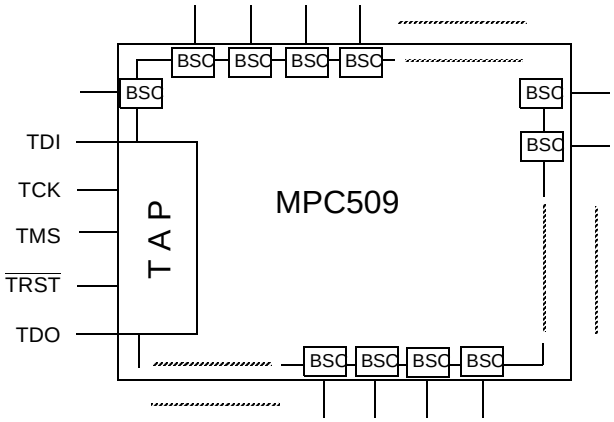


Figure 9-1 JTAG Pins

Boundary scan cells (BSC) are placed at the digital boundary of the chip (normally the package pins). The boundary scan cells are chained together to form a boundary scan register (BSR). The data is serially shifted in through the serial port (TDI) and serially shifted out through the output port (TDO).

9.1 JTAG Interface Block Diagram

A block diagram of the MPC509 implementation of the IEEE 1149.1-1990 test logic is shown in **Figure 9-2**.

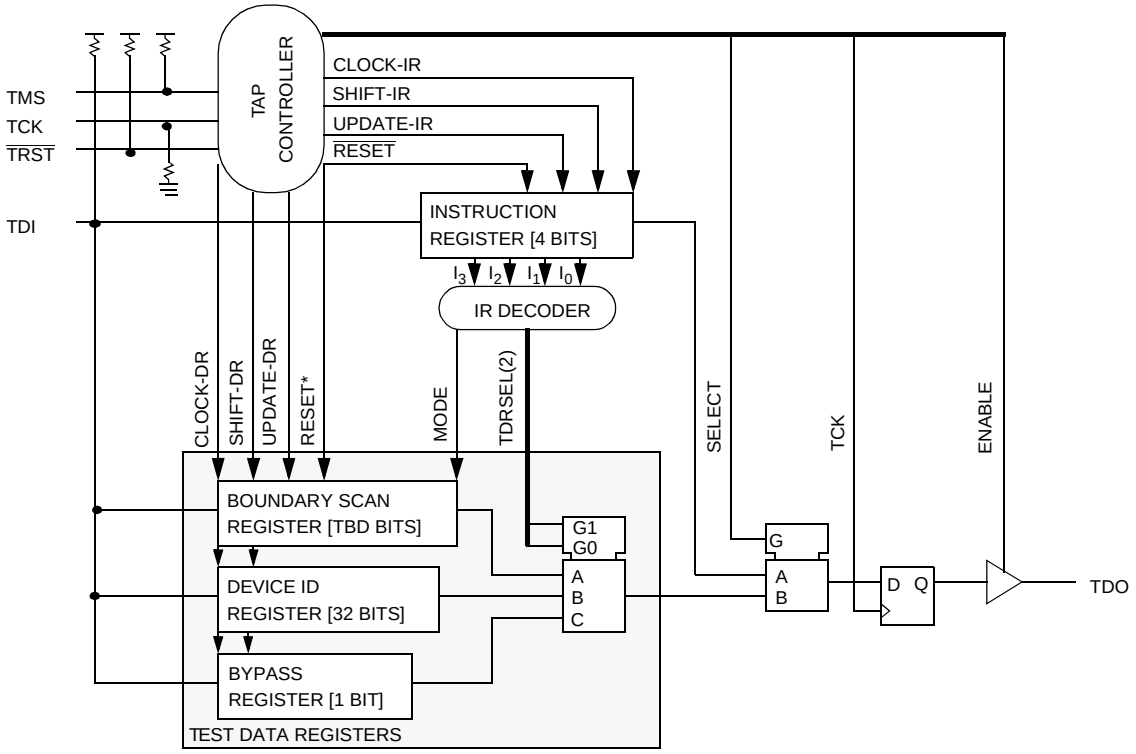


Figure 9-2 Test Logic Block Diagram

9.2 JTAG Signal Descriptions

The MPC509 has five dedicated JTAG pins, which are described in **Table 9-1**. The TDI and TDO scan ports are used to scan instructions as well as data into the various scan registers for JTAG operations. The scan operation is controlled by the test access port (TAP) controller, which in turn is controlled by the TMS input sequence.

Table 9-1 JTAG Interface Pin Descriptions

Signal Name	Input/Output	Internal Pull-Up/ Pulldown Provided	Description
TDI	Input	Pull-up	Test data input pin. Sampled on the rising edge of TCK. Has pull-up resistor.
TDO	Output	None	Test data output pin. Actively driven during the shift-IR and shift-DR controller states. Changes on the falling edge of TCK. Can be placed in high-impedance state.
TMS	Input	Pull-up	Test mode select pin. Sampled on the rising edge of TCK to sequence the test controller's state machine. Has a pull-up resistor.
TCK	Input	Pulldown	Test clock input to synchronize the test logic. Has a pull-down resistor.
TRST	Input	Pull-up	TAP controller asynchronous reset. Provides initialization of the TAP controller and other logic as required by the standard. Has a pull-up resistor.

9.3 Operating Frequency

The TCK frequency must be between 5 MHz and 10 MHz. This pin is internally driven to a low value when disconnected.

9.4 TAP Controller

$\overline{\text{TRST}}$ is used to reset the TAP controller asynchronously. The $\overline{\text{TRST}}$ pin ensures that the JTAG logic does not interfere with the normal operation of the chip. This pin is optional in the JTAG specification.

The TAP controller changes state either on the rising edge of TCK or when $\overline{\text{TRST}}$ is asserted.

The TDO signal remains in a high-impedance state except during the shift-DR or shift-IR controller states. During these controller states, TDO is updated on the falling edge of TCK.

The TAP controller states are designed as specified in the IEEE 1149.1 standard.

9.5 Instruction Register

The MPC509 implementation of the IEEE 1149.1 interface includes the three mandatory public instructions (BYPASS, SAMPLE/PRELOAD, and EXTEST) and five public instructions (CLAMP, HIGHZ, EXTEST_PULLUP, TMSCAN, and IDCODE). The MPC509 contains a four-bit instruction register without parity consisting of a shift register with four parallel outputs. Data is transferred form the shift register to the parallel outputs during update-IR controller state. The four bits are used to decode eight unique instructions as shown in **Table 9-2**.

Table 9-2 Instruction Register Encoding

Code				Instruction
B3	B2	B1	B0	
1	1	1	1	BYPASS
1	1	1	0	SAMPLE/PRELOAD
1	1	0	1	IDCODE
1	1	0	0	TMSCAN
1	0	x	x	Reserved
0	1	x	x	Reserved
0	0	1	1	CLAMP
0	0	1	0	HIGHZ
0	0	0	1	EXTEST_PULLUP
0	0	0	0	EXTEST

The parallel output of the instruction register is reset to 1101 in the Test-Logic-Reset controller state. Note that this preset state is equivalent to the IDCODE instruction. In the Capture-IR state, 1101 is loaded into the instruction shift register stage. New instructions can be shifted into the instruction shift register stage on Shift-IR state.

9.5.1 EXTEST (0000)

The external test (EXTEST) instruction enables the boundary scan register between TDI and TDO, including cells for all device signal and clock pins and associated control signals. The XTAL, EXTAL, XFC_S, XFC_C and XFC_I pins are associated with analog signals and are not included in the boundary scan register.

EXTEST also asserts internal reset for the MPC509 system logic for the duration of EXTEST in order to force a predictable internal state while performing external boundary scan operations.

By using the TAP, the boundary scan register is capable of:

- Scanning user-defined values into the output buffer;
- Capturing values presented to input signals; and
- Controlling the direction and value of bi-directional pins.

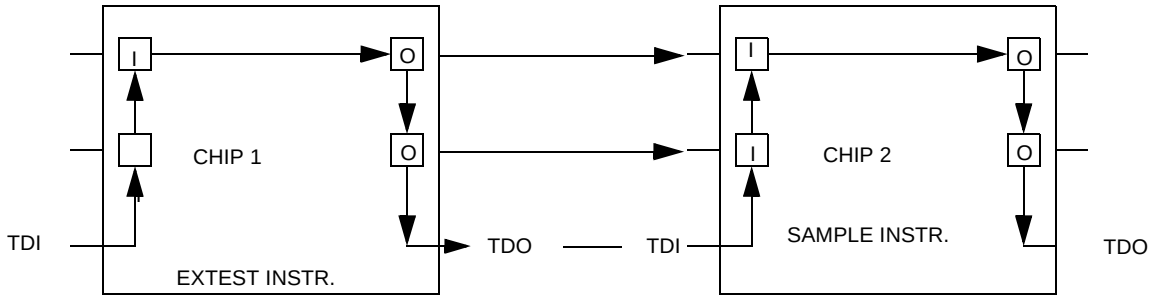


Figure 9-3 Sample EXTEST Connection

The following steps show an example of how the EXTEST instruction is initialized and invoked for board interconnection test.

1. Shift in the PRELOAD instruction in chip 1.
2. Shift in data to the boundary scan cells of chip 1 through the TDI (preload).
3. Shift the EXTEST instruction into chip 1. As soon as the Update-IR state is reached, the data in the boundary scan cells of chip 1 will be driven immediately from chip 1 into its external connections.
4. Shift the SAMPLE instruction into chip 2 to capture the logic level on the input pins including those driven by the EXTEST instruction of chip 1. Then shift the boundary scan register out to TDO for discrepancy checking.

EXTEST_PULLUP asserts internal reset for the MPC509 system logic for the duration of the instruction. This forces a predictable internal state while external boundary scan operations are performed.

9.5.2 BYPASS (1111)

The BYPASS instruction enables the single-bit BYPASS register between TDI and TDO as shown in **Figure 9-4**. This creates a shift-register path from TDI to the bypass register and finally to the TDO signal, circumventing the boundary scan register. This instruction is used to enhance test efficiency by shortening the overall path between

TDI and TDO when no test operation of a component is required. In this instruction, the MPC509 system logic is independent of the test access port. When this instruction is selected, the test logic shall have no effect on the operation of the on-chip system logic as required in the IEEE 1149.1-1990 specification.

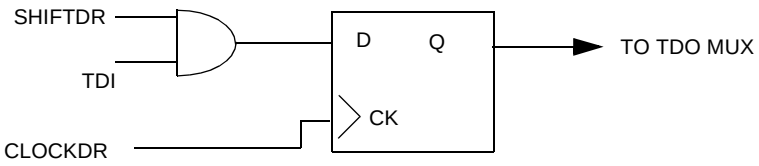


Figure 9-4 Bypass Register

9.5.3 SAMPLE/PRELOAD (1110)

The SAMPLE/PRELOAD instruction enables the boundary scan register between TDI and TDO as test data register. When this instruction is selected, the operation of the test logic shall have no effect on the operation of the on-chip system logic or on the flow of signal between the system pin and the on-chip system logic as required in the 1149.1 specification.

This instruction provides two separate functions. First, it provides a means to obtain a snapshot of system data and control signals (SAMPLE). The snapshot occurs on the rising edge of TCK in the Capture-DR controller state. The data can be observed by shifting it transparently through the boundary scan register. In a normal system configuration many signals require external pull-ups to ensure proper system operation. Consequently, the same is true for the SAMPLE/PRELOAD functionality. The data latched into the boundary scan register during the Capture-DR state may not match the drive state of the package signal if the system-required pull-ups are not present within the test environment.

The second function of the SAMPLE/PRELOAD instruction is to initialize the boundary scan register output cells (PRELOAD) prior to selection of CLAMP, EXTEST or EXTEST_PULLUP. This initialization ensures that known data will appear on the outputs when executing the EXTEST instruction. The data held in the shift register stage is transferred to the output stage on the falling edge of TCK in the Update-DR controller state.

NOTE

Since there is no internal synchronization between the IEEE 1149.1 clock (TCK) and the system clock (CLK), the user must provide some form of external synchronization to achieve meaningful results when sampling system values.

9.5.4 CLAMP (0011)

The CLAMP instruction enables the single-bit BYPASS register between TDI and TDO as test data register. It is provided as a public instruction. When the CLAMP instruction

is invoked, the package output signals will respond to the preconditioned values within the update latches of the boundary scan register, even though the bypass register is enabled as the test data register.

In-circuit testing can be facilitated by setting up guarding signal conditions that control the operation of logic not involved in the test with use of the SAMPLE/PRELOAD or EXTEST instructions. Then, as the chip enters into the CLAMP instruction, the state and drive of all signals remain static until a new instruction is invoked. While the signals continue to supply the guarding inputs to the in-circuit test site, the bypass is enabled and thus should minimize overall test time.

CLAMP asserts internal reset for the MPC509 system logic for the duration of the instruction. This forces a predictable internal state while external boundary scan operations are performed.

The CLAMP instruction performs the same task as the EXTEST instruction. Unlike the EXTEST instruction, however, once the data in the boundary scan cell is updated, it remains unchanged until a new instruction is shifted in or reset.

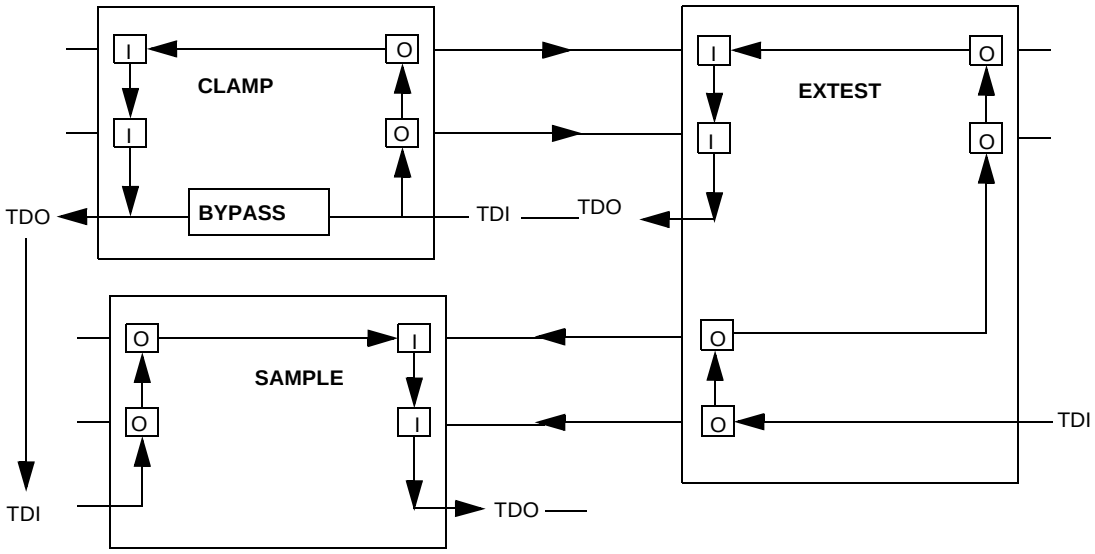


Figure 9-5 Typical Clamp Example

9.5.5 HIGHZ (0010)

The HIGHZ instruction enables the single-bit BYPASS register between TDI and TDO to function as test data register. HIGHZ is provided as a public instruction in order to avoid having to backdrive the output signals during circuit board testing. When the HIGHZ instruction is invoked, all output drivers are placed in an inactive-drive state.

HIGHZ also asserts internal reset for the MPC509 system logic for the duration of HIGHZ in order to force a predictable internal state while performing external boundary scan operations.

9.5.6 EXTEST_PULLUP (0001)

The EXTEST_PULLUP instruction is not included in the IEEE 1149.1-1990 standard. It is provided as a public instruction to aid in fault diagnosis during boundary scan testing of a circuit board. This instruction functions identically to EXTEST except for the presence of a weak pull-up device on all input signals. The MPC509 is a CMOS design and could therefore suffer from a logically indeterminate input value if an input or bi-directional signal programmed as an input was inadvertently left unconnected. The pull-up current will, given an appropriate charging delay, supply a deterministic logic 1 result on an open input.

Note that when this instruction is used in board level testing with heavily loaded nodes, it may require a charging delay greater than the two TCK periods needed to change from the Update-DR state to the Capture-DR state. Two methods of providing an increase delay are available:

- Traverse into the Run-Test/Idle state for extra TCK periods of charging delay; or
- Limit the maximum TCK frequency (slow down the TCK) so that two TCK periods are adequate

9.5.7 IDCODE (1101)

The IDCODE enables the IDREGISTER between TDI and TDO as test data register. It is provided as a public instruction to allow the manufacturer, part number, and version of a component to be determined through the TAP. **Figure 9-6** shows the IDREGISTER configuration.

Once the IDCODE instruction is decoded, it selects the IDREGISTER, a 32-bit test data register. The bypass register loads a logic 0 at the start of a scan cycle, whereas an IDREGISTER loads a constant logic 1 into its least significant bit (LSB). Examination of the first bit of data shifted out of a component during a test data scan sequence immediately following exit from the Test-Logic-Reset controller state will therefore show whether such a register is included in the design.

When the IDCODE instruction is selected, the operation of the test logic has no effect on the operation of the on-chip system logic, as required in the IEEE 1149.1-1990 specification.

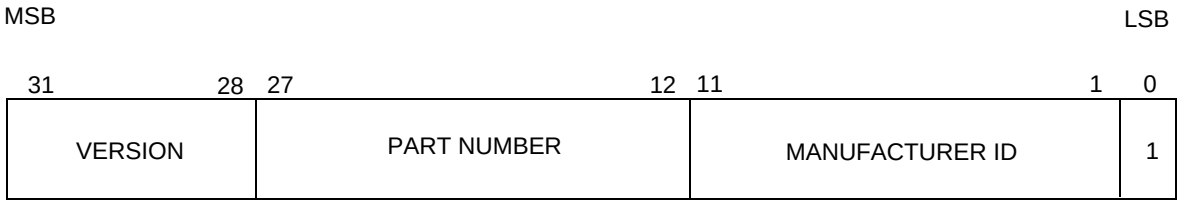


Figure 9-6 IDREGISTER Configuration

One application of the device identification register is to distinguish the manufacturer(s) of components on a board when multiple sourcing is used. As more components

emerge which conform to IEEE 1149.1-1990, it is desirable to allow for a system diagnostic controller unit to blindly interrogate a board design in order to determine the type of each component in each location. This information is also available for factory process monitoring and for failure mode analysis of assembled boards.

9.5.8 TMSCAN (1100)

The TMSCAN instruction enables the 22-bit TMREG register between TDI and TDO as test data register. It is provided as a Motorola private instruction in order to serially shift in stimulus data to the on-chip test module and serially shift out test result from the test module.

9.6 Restrictions

The control afforded by the output enable signals using the boundary scan register and the EXTEST or CLAMP instructions requires a compatible circuit board test environment to avoid device-destructive configurations. The user must avoid situations in which the MPC509 output drivers are enabled into actively driven networks.

9.7 Non-IEEE 1149.1-1990 Operation

In non-IEEE 1149.1-1990 operation, the IEEE 1149.1-1990 test logic must be kept transparent to the system logic by forcing the TAP controller into the Test-Logic-Reset controller state and keeping it there. There are two methods of forcing the controller to this state. The first is to assert the $\overline{\text{TRST}}$ signal, forcing the TAP into the Test-Logic-Reset controller state. The second is to provide at least five TCK pulses with TMS held high.

To ensure that the controller remains in the Test-Logic-Reset state, several options are available:

- If TMS either remains unconnected or is connected to Vcc, then the TAP controller cannot leave the Test-Logic-Reset state regardless of the state of the TCK pin.
- $\overline{\text{TRST}}$ can be asserted either by connecting it directly to ground or by means of a logic network.
- The controller will remain in the Test-Logic-Reset state in the absence of a rising edge on the TCK pin regardless of the state of the TMS.

9.8 Boundary Scan Descriptor Language (BSDL)

This section provides an example of the boundary scan descriptor language (BSDL).

```
-- Motorola MPC509 Model BSDL description
-- Version 1.1 Modified 11/29 by Keeho Kang to accept pad ring fixes for
cpu rev B
   entity MPC509 is
   generic(PHYSICAL_PIN_MAP:string := “XX_Package”),

-- in         = input only
-- buffer     = two-state (0 1) output
-- out        = three-state or open drain output
-- inout      = bidirectional
-- linkage    = “other” than above (power, analog, etc.)
```

```
-- bit        = single pin
-- bit_vector = multiple pins with integer suffix (a01, a1, a2, etc.)

   port(TDI:      in      bit;
        TDO:      out     bit;
        TMS:      in      bit;
        TCK:      in      bit;
        TRST_L:   in      bit;
        CS:       inout   bit_vector(0 to 11);
        CSBOOT_L: buffer  bit;
        PDWU:     buffer  bit;
        CT:       inout   bit_vector(0 to 3);
        BE_L:     inout   bit_vector(0 to 3);
        BI_L:     inout   bit;
        BURST_L:  inout   bit;
        BDIP_L:   inout   bit;
        ARETRY_L: inout   bit;
        CR_L:     inout   bit;
        ECROUT:   buffer  bit;
        CLKOUT:   buffer  bit;
        SRESET_L: buffer  bit;
        RESET_L:  in      bit;
        IRQ_L:    inout   bit_vector(0 to 6);
        DSCK:     in      bit;
        DSDI:     in      bit;
        MODCK:    in      bit;
        WP:       inout   bit_vector(0 to 5);
        VFLS:     inout   bit_vector(0 to 1);
        VF:       inout   bit_vector(0 to 2);
        PLLL:     inout   bit;
        AT:       inout   bit_vector(0 to 1);
        A:        inout   bit_vector(12 to 29);
        D:        inout   bit_vector(0 to 31);
        BB_L:     inout   bit;
        BG_L:     inout   bit;
        BR_L:     inout   bit;
        TEA_L:    inout   bit;
        TA_L:     inout   bit;
        AACK_L:   inout   bit;
        TS_L:     inout   bit;
        WR_L:     inout   bit;
        VDDKAP1:  linkage bit;
        VDDKAP2:  linkage bit;
        VSSE:     linkage bit_vector(0 to 12);
        VDDE:     linkage bit_vector(0 to 12);
        VSSIL:    linkage bit;
        VDDIL:    linkage bit;
        VSSIB:    linkage bit;
        VDDIB:    linkage bit;
        VSSIR:    linkage bit;
        VDDIR:    linkage bit;
        VSSIT:    linkage bit;
        VDDIT:    linkage bit;
        VSSSN:    linkage bit;
        VDDSN:    linkage bit;
        XFCP:     linkage bit;
        XFCN:     linkage bit;
        XTAL:     linkage bit;
        EXTAL:    linkage bit
       );
```

```
   use STD_1149_1_1990.all;

   attribute PIN_MAP of MPC509 : entity is PHYSICAL_PIN_MAP;
-- Begin package description for XX_Package
-- 160-PIN QFP  (XX Suffix)

-- package pins in same order as port list (a0, a1, a2, etc.) for
bit_vectors

   constant XX_Package : PIN_MAP_STRING :=
      "VSSE: (  1, 13, 29,  41,  60, 74, 81, 95, 107, 120, 127, 137, 153 ),
"  &
     "VDDE:  ( 160, 14, 26,  40,  61, 75, 80, 94, 106, 121, 126, 136, 152 ),
" &
       "VSSIL:    19,  "  &
       "VDDIL:    20,  "  &
       "VSSIB:    66,  "  &
       "VDDIB:    67,  "  &
       "VDDIR:   100,  "  &
       "VSSIR:   101,  "  &
       "VDDIT:   142,  "  &
       "VSSIT:   143,  "  &
       "CS:     ( 7,  6,  5,  4,  3,  2,  159, 158, 157, 156, 155,
         154),   " &
       "CSBOOT_L:    8, "  &
       "CT:     ( 12, 11, 10,  9 ),  "  &
       "BE_L:   ( 18, 17, 16, 15 ),  " &
       "CR_L:     25, "  &
       "ARETRY_L: 24, " &
       "BDIP_L:   23, "  &
       "BURST_L:  22, "  &
       "BI_L:     21, "  &
       "ECROUT:   27, "  &
       "CLKOUT:   28, "  &
       "PDWU:     30, "  &
       "VDDKAP1:  31, "  &
       "XTAL:     32, " &
       "EXTAL:    33, " &
       "VSSSN:    34, "  &
       "XFCN:     35, "  &
       "XFCP:     36, "  &
       "VDDSN:    37, "  &
       "SRESET_L: 38, "  &
       "RESET_L:  39, "  &
       "IRQ_L:  ( 43, 42, 53, 54, 55, 56, 57), "  &
       "DSCK:     44, "  &
       "DSDI:     45, "  &
       "VDDKAP2:  46, " &
       "MODCK:    47, "  &
       "TRST_L:   48,  "  &
       "TMS:      49,  "  &
       "TCK:      50,  "  &
       "TDO:      51,  "  &
       "TDI:      52,  "  &
       "WP:     (65, 64, 63, 62, 59, 58),  "  &
       "VFLS:   ( 69, 68 ),  "  &
       "VF:     ( 72, 71, 70 ), " &
       "PLLL:     73,  "  &
       "AT:     ( 77, 76 ),  " &
```

```
        "A:      ( 78, 79, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91,
          92, 93, 96, 97, 98, 99 ),   " &
        "D: (102, 103, 104, 105, 108, 109, 110, 111, 112, 113,114,
          115, 116, 117,   "  &
        "         118, 119, 122, 123, 124, 125, 128, 129, 130, 131,
          132, 133, 134, 135,   "  &
        "          138, 139, 140, 141 ),  "  &
        "BB_L:     144,  "  &
        "BG_L:     145,  "  &
        "BR_L:     146,  "  &
        "TEA_L:    147,  "  &
        "TA_L:     148,  "  &
        "AACK_L:   149,  "  &
        "TS_L:     150,  "  &
        "WR_L:     151   " ;

-- Other Pin Maps here when documented

   attribute TAP_SCAN_IN of TDI:signal is true;
   attribute TAP_SCAN_OUT of TDO:signal is true;
   attribute TAP_SCAN_MODE of TMS:signal is true;
   attribute TAP_SCAN_RESET of TRST_L:signal is true;
   attribute TAP_SCAN_CLOCK of TCK:signal is (10.0e6, BOTH);

   attribute INSTRUCTION_LENGTH of MPC509:entity is 4;

   attribute INSTRUCTION_OPCODE of MPC509:entity is
     "EXTEST         (0000),"  &
     "EXTEST_PULLUP  (0001),"  &
     "HIGHZ          (0010),"  &
     "CLAMP          (0011),"  &
     "TMSCAN         (1100),"  &
     "IDCODE         (1101),"  &
     "SAMPLE         (1110),"  &
     "BYPASS         (1111) ";

   attribute INSTRUCTION_CAPTURE of MPC509:entity is "0001";
   attribute INSTRUCTION_PRIVATE of MPC509:entity is "TMSCAN";

   attribute IDCODE_REGISTER of MPC509:entity is
     "0000" & -- version
     "000010" & -- design center
     "0000000000" & -- sequence number
     "00000001110" & -- motorola
     "1";          -- required by 1149.1

   attribute REGISTER_ACCESS of MPC509:entity is
     "BOUNDARY (EXTEST_PULLUP)  ";

   attribute BOUNDARY_CELLS of MPC509:entity is
     "BC_2, BC_4, BC_6";

   attribute BOUNDARY_LENGTH of MPC509:entity is 217;

   attribute BOUNDARY_REGISTER of MPC509:entity is

-- PORT DESCRIPTION DECODE
-- port = port name or port name with suffix such as a(1)
-- cell = BC_4 for inputs, BC_6 for bidirectionals, BC_2 all other
-- function =
--    input    = input only
```

```
--    bidir    = directional
--    controlr = control with jtag_reset
--    output2  = output two state (0 1)
-- safe =
--    X for input, output2, bidir
--    0 for control cells (0 = input)
-- ccell = controlling cell
-- dsval = disable value = 0 (0 = input)
-- rslt =  result of putting dsval in control cell = Z

   --num  cell   port      function  safe  ccell dsval rslt
   --tdo = first bit to be shifted out during ShiftDR

     “0   (BC_4, MODCK,    input,    X), “    &
     “1   (BC_4, DSDI,     input,    X), “    &
     “2   (BC_4, DSCK,     input,    X), “    &
     “3   (BC_6, IRQ_L(0), bidir,    X,       4,    0,   Z), “    &
     “4   (BC_2, *,        controlr, 0), “   &
     “5   (BC_6, IRQ_L(1), bidir,    X,       6,    0,   Z), “    &
     “6   (BC_2, *,        controlr, 0), “    &
     “7   (BC_4, RESET_L,  input,    X), “    &
     “8   (BC_2, SRESET_L, output2,  X), “    &
     “9   (BC_2, PDWU,     output2,  X), “    &
     “10  (BC_2, CLKOUT,   output2,  X), “    &
     “11  (BC_2, ECROUT,   output2,  X), “    &
     “12  (BC_6, CR_L,     bidir,    X,      13,    0,   Z), “    &
     “13  (BC_2, *,        controlr, 0), “    &
     “14  (BC_6, ARETRY_L, bidir,    X,      15,    0,   Z), “    &
     “15  (BC_2, *,        controlr, 0), “    &
     “16  (BC_6, BDIP_L,   bidir,    X,      17,    0,   Z), “    &
     “17  (BC_2, *,        controlr, 0), “    &
     “18  (BC_6, BURST_L,  bidir,    X,      19,    0,   Z), “    &
     “19  (BC_2, *,        controlr, 0), “    &
   --num  cell   port      function  safe  ccell dsval rslt
     “20  (BC_6, BI_L,     bidir,    X,      21,    0,   Z), “    &
     “21  (BC_2, *,        controlr, 0), “    &
     “22  (BC_6, BE_L(0),  bidir,    X,      23,    0,   Z), “    &
     “23  (BC_2, *,        controlr, 0), “    &
     “24  (BC_6, BE_L(1),  bidir,    X,      25,    0,   Z), “    &
     “25  (BC_2, *,        controlr, 0), “    &
     “26  (BC_6, BE_L(2),  bidir,    X,      27,    0,   Z), “    &
     “27  (BC_2, *,        controlr, 0), “    &
     “28  (BC_6, BE_L(3),  bidir,    X,      29,    0,   Z), “    &
     “29  (BC_2, *,        controlr, 0), “    &
     “30  (BC_6, CT(0),    bidir,    X,      31,    0,   Z), “    &
     “31  (BC_2, *,        controlr, 0), “     &
     “32  (BC_6, CT(1),    bidir,    X,      33,    0,   Z), “    &
     “33  (BC_2, *,        controlr, 0), “    &
     “34  (BC_6, CT(2),    bidir,    X,      35,    0,   Z), “    &
     “35  (BC_2, *,        controlr, 0), “    &
     “36  (BC_6, CT(3),    bidir,    X,      37,    0,   Z), “    &
     “37  (BC_2, *,        controlr, 0), “    &
     “38  (BC_2, CSBOOT_L,   output2,  X), “    &
     “39  (BC_6, CS(0),    bidir,    X,      40,    0,   Z), “    &
   --num  cell   port      function  safe  ccell dsval rslt
     “40  (BC_2, *,        controlr, 0), “    &
     “41  (BC_6, CS(1),    bidir,    X,      42,    0,   Z), “    &
     “42  (BC_2, *,        controlr, 0), “    &
     “43  (BC_6, CS(2),    bidir,    X,      44,    0,   Z), “    &
     “44  (BC_2, *,        controlr, 0), “    &
```

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  “45  (BC_6, CS(3),    bidir,    X,      46,    0,   Z), “    &
  “46  (BC_2, *,        controlr, 0), “    &
  “47  (BC_6, CS(4),    bidir,    X,      48,    0,   Z), “    &
  “48  (BC_2, *,        controlr, 0), “    &
  “49  (BC_6, CS(5),    bidir,    X,      50,    0,   Z), “    &
  “50  (BC_2, *,        controlr, 0), “    &
  “51  (BC_6, CS(6),    bidir,    X,      52,    0,   Z), “    &
  “52  (BC_2, *,        controlr, 0), “    &
  “53  (BC_6, CS(7),    bidir,    X,      54,    0,   Z), “    &
  “54  (BC_2, *,        controlr, 0), “    &
  “55  (BC_6, CS(8),    bidir,    X,      56,    0,   Z), “    &
  “56  (BC_2, *,        controlr, 0), “    &
  “57  (BC_6, CS(9),    bidir,    X,      58,    0,   Z), “    &
  “58  (BC_2, *,        controlr, 0), “    &
  “59  (BC_6, CS(10),   bidir,    X,      60,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “60  (BC_2, *,        controlr, 0), “    &
  “61  (BC_6, CS(11),   bidir,    X,      62,    0,   Z), “    &
  “62  (BC_2, *,        controlr, 0), “    &
  “63  (BC_6, WR_L,     bidir,    X,      64,    0,   Z), “    &
  “64  (BC_2, *,        controlr, 0), “    &
  “65  (BC_6, TS_L,     bidir,    X,      66,    0,   Z), “    &
  “66  (BC_2, *,        controlr, 0), “    &
  “67  (BC_6, AACK_L,   bidir,    X,      68,    0,   Z), “    &
  “68  (BC_2, *,        controlr, 0), “    &
  “69  (BC_6, TA_L,     bidir,    X,      70,    0,   Z), “    &
  “70  (BC_2, *,        controlr, 0), “    &
  “71  (BC_6, TEA_L,    bidir,    X,      72,    0,   Z), “    &
  “72  (BC_2, *,        controlr, 0), “    &
  “73  (BC_6, BR_L,     bidir,    X,      74,    0,   Z), “    &
  “74  (BC_2, *,        controlr, 0), “    &
  “75  (BC_6, BG_L,     bidir,    X,      76,    0,   Z), “    &
  “76  (BC_2, *,        controlr, 0), “    &
  “77  (BC_6, BB_L,     bidir,    X,      78,    0,   Z), “    &
  “78  (BC_2, *,        controlr, 0), “    &
  “79  (BC_6, D(31),    bidir,    X,      80,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “80  (BC_2, *,        controlr, 0), “    &
  “81  (BC_6, D(30),    bidir,    X,      82,    0,   Z), “    &
  “82  (BC_2, *,        controlr, 0), “    &
  “83  (BC_6, D(29),    bidir,    X,      84,    0,   Z), “    &
  “84  (BC_2, *,        controlr, 0), “    &
  “85  (BC_6, D(28),    bidir,    X,      86,    0,   Z), “    &
  “86  (BC_2, *,        controlr, 0), “    &
  “87  (BC_6, D(27),    bidir,    X,      88,    0,   Z), “    &
  “88  (BC_2, *,        controlr, 0), “    &
  “89  (BC_6, D(26),    bidir,    X,      90,    0,   Z), “    &
  “90  (BC_2, *,        controlr, 0), “    &
  “91  (BC_6, D(25),    bidir,    X,      92,    0,   Z), “    &
  “92  (BC_2, *,        controlr, 0), “    &
  “93  (BC_6, D(24),    bidir,    X,      94,    0,   Z), “    &
  “94  (BC_2, *,        controlr, 0), “    &
  “95  (BC_6, D(23),    bidir,    X,      96,    0,   Z), “    &
  “96  (BC_2, *,        controlr, 0), “    &
  “97  (BC_6, D(22),    bidir,    X,      98,    0,   Z), “    &
  “98  (BC_2, *,        controlr, 0), “    &
  “99  (BC_6, D(21),    bidir,    X,     100,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “100 (BC_2, *,        controlr, 0), “    &
  “101 (BC_6, D(20),    bidir,    X,     102,    0,   Z), “    &
```

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  “102 (BC_2, *,       controlr, 0), “    &
  “103 (BC_6, D(19),   bidir,    X,     104,    0,   Z), “    &
  “104 (BC_2, *,       controlr, 0), “    &
  “105 (BC_6, D(18),   bidir,    X,     106,    0,   Z), “    &
  “106 (BC_2, *,       controlr, 0), “    &
  “107 (BC_6, D(17),   bidir,    X,     108,    0,   Z), “    &
  “108 (BC_2, *,       controlr, 0), “    &
  “109 (BC_6, D(16),   bidir,    X,     110,    0,   Z), “    &
  “110 (BC_2, *,       controlr, 0), “    &
  “111 (BC_6, D(15),   bidir,    X,     112,    0,   Z), “    &
  “112 (BC_2, *,       controlr, 0), “    &
  “113 (BC_6, D(14),   bidir,    X,     114,    0,   Z), “    &
  “114 (BC_2, *,       controlr, 0), “    &
  “115 (BC_6, D(13),   bidir,    X,     116,    0,   Z), “    &
  “116 (BC_2, *,       controlr, 0), “    &
  “117 (BC_6, D(12),   bidir,    X,     118,    0,   Z), “    &
  “118 (BC_2, *,       controlr, 0), “    &
  “119 (BC_6, D(11),   bidir,    X,     120,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “120 (BC_2, *,       controlr, 0), “    &
  “121 (BC_6, D(10),   bidir,    X,     122,    0,   Z), “    &
  “122 (BC_2, *,       controlr, 0), “    &
  “123 (BC_6, D(9),    bidir,    X,     124,    0,   Z), “    &
  “124 (BC_2, *,       controlr, 0), “    &
  “125 (BC_6, D(8),    bidir,    X,     126,    0,   Z), “    &
  “126 (BC_2, *,       controlr, 0), “    &
  “127 (BC_6, D(7),    bidir,    X,     128,    0,   Z), “    &
  “128 (BC_2, *,       controlr, 0), “    &
  “129 (BC_6, D(6),    bidir,    X,     130,    0,   Z), “    &
  “130 (BC_2, *,       controlr, 0), “    &
  “131 (BC_6, D(5),    bidir,    X,     132,    0,   Z), “    &
  “132 (BC_2, *,       controlr, 0), “    &
  “133 (BC_6, D(4),    bidir,    X,     134,    0,   Z), “    &
  “134 (BC_2, *,       controlr, 0), “    &
  “135 (BC_6, D(3),    bidir,    X,     136,    0,   Z), “    &
  “136 (BC_2, *,       controlr, 0), “    &
  “137 (BC_6, D(2),    bidir,    X,     138,    0,   Z), “    &
  “138 (BC_2, *,       controlr, 0), “    &
  “139 (BC_6, D(1),    bidir,    X,     140,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “140 (BC_2, *,       controlr, 0), “    &
  “141 (BC_6, D(0),    bidir,    X,     142,    0,   Z), “    &
  “142 (BC_2, *,       controlr, 0), “    &
  “143 (BC_6, A(29),   bidir,    X,     144,    0,   Z), “    &
  “144 (BC_2, *,       controlr, 0), “    &
  “145 (BC_6, A(28),   bidir,    X,     146,    0,   Z), “    &
  “146 (BC_2, *,       controlr, 0), “    &
  “147 (BC_6, A(27),   bidir,    X,     148,    0,   Z), “    &
  “148 (BC_2, *,       controlr, 0), “    &
  “149 (BC_6, A(26),   bidir,    X,     150,    0,   Z), “    &
  “150 (BC_2, *,       controlr, 0), “    &
  “151 (BC_6, A(25),   bidir,    X,     152,    0,   Z), “    &
  “152 (BC_2, *,       controlr, 0), “    &
  “153 (BC_6, A(24),   bidir,    X,     154,    0,   Z), “    &
  “154 (BC_2, *,       controlr, 0), “    &
  “155 (BC_6, A(23),   bidir,    X,     156,    0,   Z), “    &
  “156 (BC_2, *,       controlr, 0), “    &
  “157 (BC_6, A(22),   bidir,    X,     158,    0,   Z), “    &
  “158 (BC_2, *,       controlr, 0), “    &
  “159 (BC_6, A(21),   bidir,    X,     160,    0,   Z), “    &
```

```
--num  cell   port      function  safe  ccell dsval rslt
  “160 (BC_2, *,        controlr, 0), “    &
  “161 (BC_6, A(20),    bidir,    X,     162,    0,   Z), “    &
  “162 (BC_2, *,        controlr, 0), “    &
  “163 (BC_6, A(19),    bidir,    X,     164,    0,   Z), “    &
  “164 (BC_2, *,        controlr, 0), “    &
  “165 (BC_6, A(18),    bidir,    X,     166,    0,   Z), “    &
  “166 (BC_2, *,        controlr, 0), “    &
  “167 (BC_6, A(17),    bidir,    X,     168,    0,   Z), “    &
  “168 (BC_2, *,        controlr, 0), “    &
  “169 (BC_6, A(16),    bidir,    X,     170,    0,   Z), “    &
  “170 (BC_2, *,        controlr, 0), “    &
  “171 (BC_6, A(15),    bidir,    X,     172,    0,   Z), “    &
  “172 (BC_2, *,        controlr, 0), “    &
  “173 (BC_6, A(14),    bidir,    X,     174,    0,   Z), “    &
  “174 (BC_2, *,        controlr, 0), “    &
  “175 (BC_6, A(13),    bidir,    X,     176,    0,   Z), “    &
  “176 (BC_2, *,        controlr, 0), “    &
  “177 (BC_6, A(12),    bidir,    X,     178,    0,   Z), “    &
  “178 (BC_2, *,        controlr, 0), “    &
  “179 (BC_6, AT(0),    bidir,    X,     180,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “180 (BC_2, *,        controlr, 0), “    &
  “181 (BC_6, AT(1),    bidir,    X,     182,    0,   Z), “    &
  “182 (BC_2, *,        controlr, 0), “    &
  “183 (BC_6, PLLL,     bidir,    X,     184,    0,   Z), “    &
  “184 (BC_2, *,        controlr, 0), “    &
  “185 (BC_6, VF(0),    bidir,    X,     186,    0,   Z), “    &
  “186 (BC_2, *,        controlr, 0), “    &
  “187 (BC_6, VF(1),    bidir,    X,     188,    0,   Z), “    &
  “188 (BC_2, *,        controlr, 0), “    &
  “189 (BC_6, VF(2),    bidir,    X,     190,    0,   Z), “    &
  “190 (BC_2, *,        controlr, 0), “    &
  “191 (BC_6, VFLS(0),  bidir,    X,     192,    0,   Z), “    &
  “192 (BC_2, *,        controlr, 0), “    &
  “193 (BC_6, VFLS(1),  bidir,    X,     194,    0,   Z), “    &
  “194 (BC_2, *,        controlr, 0), “    &
  “195 (BC_6, WP(0),    bidir,    X,     196,    0,   Z), “    &
  “196 (BC_2, *,        controlr, 0), “    &
  “197 (BC_6, WP(1),    bidir,    X,     198,    0,   Z), “    &
  “198 (BC_2, *,        controlr, 0), “    &
  “199 (BC_6, WP(2),    bidir,    X,     200,    0,   Z), “    &
--num  cell   port      function  safe  ccell dsval rslt
  “200 (BC_2, *,        controlr, 0), “    &
  “201 (BC_6, WP(3),    bidir,    X,     202,    0,   Z), “    &
  “202 (BC_2, *,        controlr, 0), “    &
  “203 (BC_6, WP(4),    bidir,    X,     204,    0,   Z), “    &
  “204 (BC_2, *,        controlr, 0), “    &
  “205 (BC_6, WP(5),    bidir,    X,     206,    0,   Z), “    &
  “206 (BC_2, *,        controlr, 0), “    &
  “207 (BC_6, IRQ_L(2), bidir,    X,     208,    0,   Z), “    &
  “208 (BC_2, *,        controlr, 0), “    &
  “209 (BC_6, IRQ_L(3), bidir,    X,     210,    0,   Z), “    &
  “210 (BC_2, *,        controlr, 0), “    &
  “211 (BC_6, IRQ_L(4), bidir,    X,     212,    0,   Z), “    &
  “212 (BC_2, *,        controlr, 0), “    &
  “213 (BC_6, IRQ_L(5), bidir,    X,     214,    0,   Z), “    &
  “214 (BC_2, *,        controlr, 0), “    &
  “215 (BC_6, IRQ_L(6), bidir,    X,     216,    0,   Z), “    &
  “216 (BC_2, *,        controlr, 0)  “    ;
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